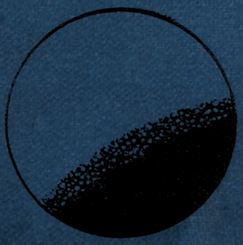
CELESTIAL MOTIONS

A HANDY BOOK
OF
ASTRONOMY.



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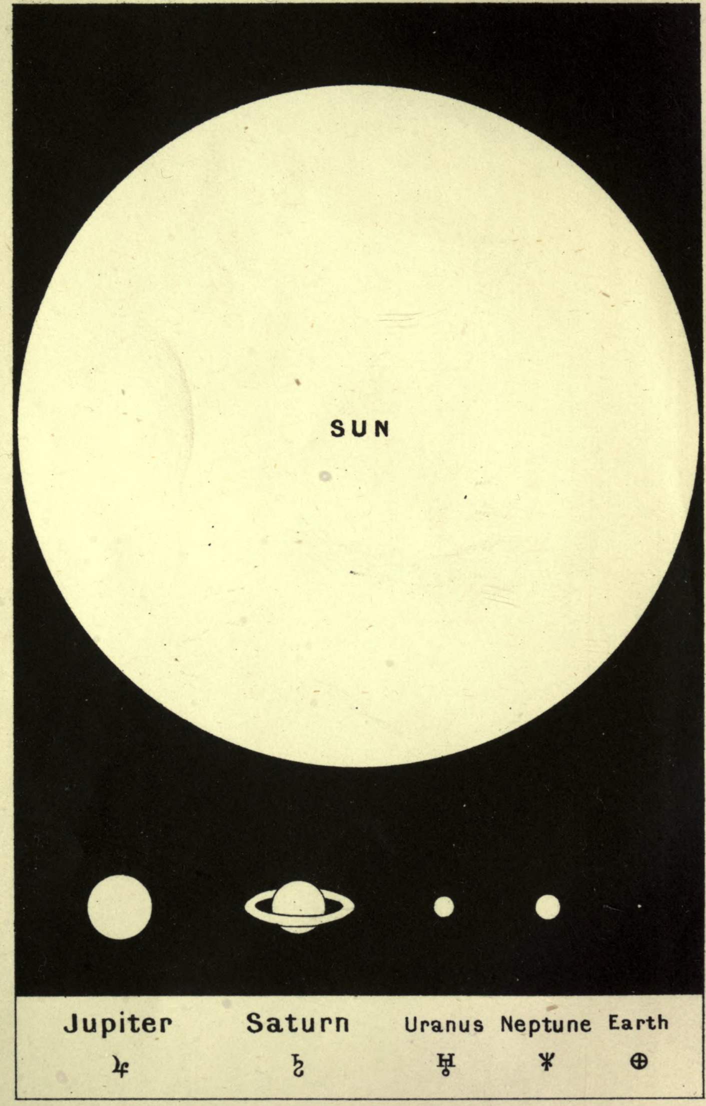
CELESTIAL MOTIONS.

COMPARATIVE SIZES OF THE SUN & PRINCIPAL PLANETS.


SUN
Jupiter
♃
Saturn
♄
Uranus
♅
Neptune
♆
Earth
⊕

Mercury ☿, Venus ♀, and Mars ♂, drawn to same scale, would be mere dots, being smaller than the Earth.

Astron.
L

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CELESTIAL MOTIONS:

A
HANDY BOOK
OF

ASTRONOMY.

BY
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WITH THREE PLATES.

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1889.

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"Lift up your eyes on high, and behold Who hath created these things, that bringeth out their host by number; He calleth them all by names by the greatness of His might, for that He is strong in power; not one faileth."—*Isaiah* xl. 26.

" Laudate eum, Harmoniæ cœlestes."—*Kepler.*

" These are Thy glorious works, Parent of good,
Almighty! Thine this universal frame,
Thus wondrous fair: Thyself how wondrous then!"
Milton.

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PREFACE.

THIS little treatise is not intended in any way as a substitute for other and larger works on astronomy. But the author was induced to think that a concise digest of the most important facts which have been discovered regarding the motions of the celestial bodies, and the dimensions of those belonging to our our own system, might be useful to many persons who take an interest in the science. Particular care has been exerted to render the information given the most recent which is available at the time of publication.

W. T. L.

BLACKHEATH, *March* 1*st*, 1884.

In this sixth edition, the work has again been thoroughly revised, and the information brought up to its date. The form and arrangement have also been in some respects altered, and a chapter has been added on 'The Calendar,' some reference to which subject appeared appropriate in an astronomical treatise.

W. T. L.

BLACKHEATH, *May* 1*st*, 1889.

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CELESTIAL MOTIONS.

CHAPTER I.

THE EARTH.

THE general shape of the Earth on which we live is that of a sphere or globe. Although the irregularities of its surface present in places what appear, to our eyes, enormous elevations, the altitude of the highest mountain does not really amount to nearly the thousandth part of the diameter of the Earth; and the depth of the lowest sea-bottom is about the same as the height of the highest mountain. But although our powers of locomotion are thus confined within so comparatively small a part of the vast universe of creation, the wonderful sense of sight has enabled us to acquire, through the agency of light, some knowledge of other bodies around us, many of which are seen to be in motion, though science has taught us that these motions are not all real, but partly apparent, produced by real motions of the Earth itself, of which we inhabit a portion of the surface. All the knowledge which we have acquired or can acquire respecting these bodies is embraced under the term astronomy ; and as that science has taught us to consider the Earth itself as one of the moving bodies of the universe (one of the planets, in fact, revolving round the Sun, from which they derive their light and heat), a knowledge of its motions, as well as of its shape and size, forms also a part, and an important part, of astronomy ; and to it this first chapter is devoted.

Its form then is very nearly, but not quite, spherical, being slightly flattened at the poles, the diameter taken anywhere across the equator measuring about 7926 miles, and the polar diameter, or that taken from pole to pole, about 7899 miles, twenty-seven less than the equatorial. On the polar diameter, as an axis, the Earth rotates from west to east, whilst revolving in the same direction in an orbit round the sun ; the axis being inclined to the plane of this orbit at an angle of 66° 32′. The axial rotation is performed in what is called a sidereal day, which contains $23^{h}\ 56^{m}\ 4^{s}\cdot09$ of our ordinary time. For the day (divided into twenty-four hours) of our ordinary reckoning is a **solar** day, as the convenience of life renders it necessary to regulate our time by the Sun, and, in consequence of the Earth's annual motion round that body, the period of revolution between two successive similar positions relatively to him is a little longer than that between two which are similar relatively to the same point in the heavens, the latter interval constituting a sidereal day. The ordinary or solar day is in strictness of varying length, owing to the Earth's unequal motion in different parts of its orbit; but in practice a mean or average one for the whole year is adopted and called a mean solar day, and this is the unit of time in all other astronomical measurements of duration.

Of these mean solar days, then, the Earth occupies 365·25636 (equal to $365^d\ 6^h\ 9^m\ 9^s$) in revolving round the Sun. But as the conveniences of life lead us to take for a day not the precise period of time in which the Earth rotates on its axis, so do they compel us to adopt for one year not the exact period of time in which the Earth revolves in its orbit. For what makes the observance of the year necessary to us is the change produced by the variations in the seasons; and, in consequence of a slow gyratory movement of the Earth's axis (occupying about 25,800 years to complete a whole round), which goes under the name of the precession of the equinoxes, from the effect it produces upon the equinoctial points, the tropical year, in which all the changes of the seasons are run through, is somewhat shorter than the sidereal year, or the actual duration of the Earth's revolution round the Sun. The length in fact of the tropical year (which is what is ordinarily meant by a year) is $365^{d} \cdot 24220$, or $365^{d}\ 5^{h}\ 48^{m}\ 46^{s}$. It would be so extremely awkward to make a year consist of a number of days and a fraction of a day that the difficulty is got over by adopting in the calendar **two** years: one called a common year, which consists of 365 days, and an occasional one called a bissextile or leap year, which consists of 366 days. By the old Julian reckoning, which erroneously supposed the year to contain 365¼ days exactly, every fourth year was reckoned as one of the latter, and each year which was divisible by four without remainder was considered to be a leap-year, an extra day being added on in the month of February. But by the Gregorian reckoning, introduced into England in 1752, a leap-year is dropped at the end of each century, except at the end of each fourth century (*e.g.*

1900 will not be a leap-year, but 2000 will). This is equivalent to considering the year to consist of 365·24250 days, differing by only the fraction 0·00030 of a day, or about 26^s, from its true value, 365·24220 days. This small difference will not by accumulation amount to an entire day for more than 3000 years.

It will be seen from the above that the Earth has three principal motions: (1) a rotation of the globe round its own axis, (2) a revolution round the Sun, during which the axis remains nearly parallel to itself throughout, and (3) a slow gyratory motion of the axis so performed as to retain nearly the same inclination to the plane of the orbit throughout. But it should be mentioned that the last is subject to a periodic oscillation (the period of which is a little less than nineteen years), which alternately slightly increases and diminishes the inclination in question. This is called the nutation of the Earth's axis, and was discovered by Dr. Bradley, the third Astronomer Royal, in the year 1747.

The mean density of the Earth is about five-and-a-half times that of water; which shows that some portion at least of the interior must be much denser than that of the exterior crust. The area of the whole surface of our planet is about 197,000,000 square miles. Of this about three-fourths, or 145,000,000 square miles, are covered by water ; and the fact that the area of water in the southern hemisphere is larger than that in the northern proves that the former portion of the Earth is somewhat denser than the latter, enabling it to retain the larger bulk of water. If the surface of the globe be divided into two hemispheres such that the surface of one contains the largest possible amount of land, and the other the largest possible amount of water, the centre of the former portion will be very near the British Islands, and that of the other very near New Zealand.

CHAPTER II.

THE MOON.

In its annual journey round the Sun, the Earth is accompanied by a smaller planet called the Moon, the movement of which relatively to the Earth being in the nature of a motion in an elliptic orbit round the latter, she is considered as a satellite or secondary planet thereto. The Moon, then, being by far our nearest neighbour amongst the heavenly bodies, much more has been learnt about her than about the others. Selenography in fact, or the knowledge and description of the surface of the Moon, has become of recent years almost a science of itself. The great work of Beer and Mädler upon it was published in the year 1837 ; that of Mr. Neison * in 1876. But we do not here propose to enter in the smallest degree upon this or kindred topics. On account of the Moon's close proximity to us, as compared with the distances of other heavenly bodies, an exact

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* Now Her Majesty's Astronomer at Natal. He has changed his name to Neville Nevill.

knowledge of her apparent motion amongst the stars is of the greatest practical use in navigation, for enabling the mariner to find his longitude at sea. The difficulty of this problem, which has exercised the labours of many distinguished mathematicians, arises from the perturbations to which the Moon's elliptic motion round the Earth is subjected through the gravitating action of the Sun and even of some of the planets. By reason indeed of the much greater mass of the Sun, he exerts a more powerful attractive force upon the Moon than the Earth does, although the latter is so much nearer. Exception, therefore, has been taken to calling the Moon a satellite of the Earth ; and she is certainly not so quite in the sense that the satellites of Jupiter and Saturn are of those planets. Still, as we have said, her motion, relatively to the Earth, is a motion round it ; she is connected with our planet by an indissoluble tie, and, from her great benefit to us, will always be called our satellite, exciting our gratitude, and commanding our attention.

The actual duration of the Moon's orbital motion round the Earth is $27^{d}\ 7^{h}\ 43^{m}\ 11^{s}{\cdot}5$; but here again the convenience of life compels us to regard as a lunar month or lunation not this, the sidereal time of her revolution, but the period in which she revolves from being nearly in the same direction as the Sun to the same again. This, which is sometimes called a synodic revolution, amounts to $29^{d}\ 12^{h}\ 44^{m}\ 2^{s}\cdot 7$; upon it of course depend the Moon's phases as presented to the Earth, her light being reflected solar light. She also receives solar light reflected from the Earth; and at certain times, when the illuminated part of the Earth turned towards her is the greatest (*i. e.*, near our New Moon), this is sufficiently strong to be reflected back again, enabling us to see the other part of her surface, as at Full Moon, only very faint. This is popularly called "the old Moon in the young Moon's arms."

Another consequence of the Moon's comparatively great proximity is that her distance and size can be determined much more accurately than those of any other heavenly body. Her distance varies in different parts of her orbit from 221,600 to 253,000 miles; the mean horizontal parallax being about $57'\ 2''$, and the resulting mean distance about 237,300 miles. The eccentricity of the Moon's orbit is about 0·0662; the value of its mean inclination to the ecliptic, or earth's orbit, varies between 5° 0′ and 5° 17′, the mean value being 5° 8′ 40″.

The diameter of the Moon is about 2160 miles, or somewhat less than two-sevenths that of the Earth; so that the bulk of the latter is about fifty times as great as that of the Moon. But her density being little more than half that of our own globe, her mass amounts to only about one-eightieth that of the Earth.

The Moon rotates on her axis very much more slowly than our Earth does. In fact the duration of her rotation is exactly the same as that of her revolution round the Earth. The consequence is that we always see precisely the same face of the Moon; the whole of one-half of her surface being always concealed from us, excepting such small portions of it near the visible half which come into view from librations (as they are called) produced by the varying velocity of her orbital motion and the inclination of her orbit to that of the Earth.

That portion of the Moon's surface which we are able to see and study presents a very different appearance to what any portion of the Earth's surface would do if similarly scrutinised. All indications show that there is no atmosphere surrounding the Moon; or at least, that if there be any, it must be of excessive tenuity and unable to hold clouds, or any appreciable amount of aqueous vapour, in suspension. Indeed, if there be any water on the surface of our satellite, it must be very trifling in amount, and only existing in the lowest depressions, yet there is decisive evidence of the action of water on the lunar surface in bygone ages, so that this has probably in the course of time been all absorbed into the interior, or has become by degrees chemically combined with the solid material of the exterior. At present the surface is solely diversified by mountainous chains and ranges (over which are dispersed a large number of crateriform cavities, many of them containing a conical hill at the bottom) and extensive arid plains which retain the name of seas, given them when selenography was in its infancy, and when it was erroneously thought that they were really covered by water. Formations of a very peculiar character have also been noticed in comparatively recent times, consisting of long streaks running across other formations; these, which are called rills, are usually supposed to be the results of crackings in the surface, but it has been suggested that they may be dried water-courses.

CHAPTER III.

THE SUN.

A VOLUME many times larger than this might be written upon the different determinations which have been made of the Sun's parallax and distance. To measure these with accuracy is difficult on account of the Sun's great distance compared with the size of the Earth, so that a small error in the measured parallax produces a large error in the resulting distance. On our knowledge of this depends that of all other magnitudes in the solar system, besides which it is the unit of any approximate measures we are able to take beyond it. For by Kepler's third law, the proportions of the distances of all the bodies moving round the Sun are known exactly from their periodic times of revolution, so that if the Earth's distance be known, those of all the planets can be deduced by a very simple piece of arithmetic. We do not intend here to treat of the history of the measurements of the Sun's parallax, but merely to give the result of the most recent determinations. From the time of Flamsteed, it has been known that it is so small as not to exceed 10″. Halley pointed out the advantage that might be gained by observing the transits of Venus on those rare occasions when she passes at inferior conjunction over the Sun's disc. The transits of 1761 and 1769 were accordingly observed by a large number of parties sent to different parts of the world for the purpose. But the solution of the problem in this manner is encompassed by practical difficulties. Many results were obtained by calculation from the observations of the transits of those years; but for a long time it was agreed amongst astronomers that the value obtained by Encke, which amounted to 8″·57, was the best. More recently many considerations have led them to believe that this is somewhat too small. Determinations made by observing Mars (which when in opposition approaches us sometimes almost as closely as Venus does in inferior conjunction), and by other methods, have shown that the Sun's parallax is probably greater by at least 0″·2 than Encke's value for it. Moreover, it was pointed out by Mr. Stone* that the latter was affected by erroneous interpretations of some of the observations, and that, when these are rightly explained, they also give a value considerably larger than Encke's. The observations of the more recent transits in 1874 and 1882 likewise (although the method is somewhat discredited, as compared with other methods, on account of its practical difficulties) prove to be most consistent with the value of about 8″·80. Dr. Gill, from his skilful observations of Mars in Ascension Island during that planet's favourable opposition in 1877, obtained a value only 0″·02 smaller than this, amounting to 8″·78, which gives for the Sun's mean distance very nearly 93,000,000 miles,—probably within a quarter of a million of miles of its true value. But it most be noted, that in consequence of the eccentricity of the Earth's orbit (which amounts to 0·01679), the Sun's actual distance varies between a million and a half miles less, and a million and a half miles more than this ; being least when the Earth is at that end of the major axis of its orbit which is nearest the focus occupied by the Sun, and greatest when the Earth is at the other end of that axis, these two points being called respectively the perihelion and the aphelion of the Earth's orbit.*

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* Now "Radcliffe Observer," *i.e.*, Director of the Radcliffe Observatory at Oxford.

Accepting, then, 93,000,000 miles as the Sun's mean distance from us, it is easy to find, by observing his apparent diameter, that his real diameter is about 866,000 miles. This is about 109 times as great as the Earth's, so that the Sun's volume is able to contain the Earth's about 1,306,000 times over. But the comparative effects of their attractive forces show that the Sun's mass is only about 332,260 times as great as that of the Earth. Consequently his density must amount to only about 0·25 that of the Earth.

The shape of the Sun would seem to be that of a perfect sphere. As soon as he was observed through a telescope it was seen that his surface is usually diversified by a number of black spots of varying dimensions and appearances. The motions of these made it evident that the Sun is endued with a stately rotation on his axis. These motions are such as would carry a spot from first appearing on the Sun's disc to appearing there again (if persistent enough to do so) in about 27 days; hence, taking into account the simultaneous motion of the Earth in its orbit round the Sun, it was inferred that the Sun turns on his axis in about $25^d\ 7^h$. It should be stated, however, that recent observations have shown that the spots nearer the Sun's equator move somewhat more rapidly than those farther from it. Spots are very seldom seen at a greater distance from the Sun's equator than about 30° on either side of it; and those at that distance take as much as $26\frac{1}{2}$ days to move round the surface.

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* When the Earth is in perihelion, the Sun is said to be in perigee; when the Earth is in aphelion, the Sun is in apogee. The times of the year at which these take place are subject to a slow change; at present the former (when the Sun is nearest to the Earth) occurs at the beginning of January, and the latter (when the Earth is farthest from the Sun) early in July.

One other point concerning the spots may be mentioned here; we mean their periodicity. This was first noticed by Schwabe of Dessau about sixty years ago; the subject has since attracted much attention, and the period, so far as it is constant, is now pretty accurately determined to be a little more than eleven years. The last epoch of maximum of abundance and frequency, which was more than usually protracted, was in 1882; and as the diminution is generally less rapid than the increase, we may expect that the present year (1889) will be one of minimum, and that the next maximum will take place about 1893.

The solar spots are produced by tearings open of some of the luminous envelopes which surround the Sun, so that we see in them to a depth below that of the ordinary surface. In their immediate neighbourhood there are often to be seen patches of more than usual brightness (heapings up, so to speak, of luminous matter) which are called *faculæ*, the Latin word for *torches*. Both phenomena indicate activity and commotion going on in the outer part (and to some unknown depth below) of the Sun's surface. Other manifestations of this have been recognised in tremendous rushes of gaseous matter, moving with enormous velocities, to great heights above the solar surface. Modern instruments and methods of investigation have enabled astronomers to trace the action and course of these at any time when they are in progress; but the appearances afterwards found to be due to them were first perceived on the occurrence of total eclipses of the Sun. They were long called red flames, or rose-coloured protuberances, and attention was first attracted to them during the eclipse which was total in Switzerland in the year

1706. It was long contested whether they belonged to the Sun or to the Moon, the dark body of which concealed the Sun during a total eclipse, and it was then thought that she might be surrounded by an atmosphere in which these phenomena appeared. But the careful observations made during later eclipses (particularly at those which were total in Norway and Sweden in 1851, and in Spain in 1860, and were observed by Sir George Airy and many other astronomers) showed clearly, from the way in which they were first covered and then uncovered by the Moon, that they were in fact appendages of the Sun. The plan of this treatise does not admit of our entering further into this subject here.

CHAPTER IV.

THE SOLAR SYSTEM.

THE Earth on which we live is one of a large number of bodies which circulate in orbits round the Sun, being attracted to him by a force called gravitation, which, constant in itself, acts in such a way that its effect diminishes as the square of the distance increases. The revolving bodies themselves are endued with a similar attracting energy, but much smaller than that of the Sun in consequence of the much smaller amount of matter which they contain. The Sun, the central body of this great system, diffuses by radiation light and heat through the whole with an intensity which diminishes, like the force of gravity, in the same proportion as the square of the distance increases.

The bodies which are known to revolve round the Sun are divided into three classes, planets, comets, and meteoroids, or swarms of meteors, which travel in vast shoals together along orbits similar to those of comets, with which they seem to have some kind of connection, not yet fully understood. The planets vary very much in size, the largest (Jupiter) being more than a thousand times as large as our Earth, whilst many of the small planets are so minute as to be only visible with the aid of powerful telescopes, so that it is impossible to measure their real sizes. These small planets, however, which have only been discovered since the beginning of the present century, form almost a class of themselves. All the planets revolve round the Sun in elliptical orbits of small eccentricity, which do not differ greatly from circles. These orbits are inclined at various angles to the plane of the Earth's orbit, and those of a few of the small planets at angles considerably greater than those of the large planets. In like manner the eccentricities of the orbits of a few of the small planets are much greater than those of the orbits of any of the large planets. But all the planets, large or small, move in the same general direction in their orbits. Comets (at least those which form permanent members of the system) also revolve round the Sun in elliptic orbits, but the inclination and eccentricity of these are in many instances much greater than those of the planetary orbits, and many of those which revolve in very elongated ellipses, move in the reverse direction to that of all the planets. Meteoroids, or swarms of meteors which move in regular orbits, revolve in paths like those of comets, several of them in orbits nearly identical with some cometary orbits ; and indeed it would seem not unlikely that many comets consist in fact of clusters of meteors, loosely kept near together by the feeble bond of the attraction of the separate particles, similar particles being scattered along the whole or a part of the orbit, but more thickly congregated together in some portions than in others.

The large planets are eight in number : Mercury, Venus, the Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. It has been often surmised that there is a planet (or possibly several planets) nearer the sun than Mercury ; but if so this body, or these bodies, must be very small, and none has yet been proved to exist. Whether there be a planet more distant from the Sun than Neptune it is impossible at present to say. Such a body would probably not be visible without the aid of a powerful telescope. Only a small proportion of the faint stars which become visible with such aid have been observed continuously so as to ascertain whether their motions show that they are within our system ; of these hundreds have been found to do so, but their faintness arises, not from their great distance, but from their really small size, and their mean distances are all smaller than that of Jupiter, though greater than that of Mars.

CHAPTER V.

THE PLANETS.

THE laws according to which the planets move in the same general direction round the Sun were discovered by Kepler, and are therefore called Kepler's Laws. The first of these is that their orbits are ellipses with the Sun in one focus ; the second that they move fastest when nearest the Sun in such a way that the radius vector (an imaginary line drawn from the Sun to the planet's place at any time) sweeps over areas of the ellipse proportional to the time of sweeping ; the third that the squares of the periodic times of their revolutions round the Sun are proportional to the cubes of their mean distances from him. The first two of these laws were shown by Newton to be necessary consequences of their being attracted by the Sun with a force varying inversely as the square of the distance ; the third proves that the force by which they are attracted towards the Sun is the same upon each, the actual intensity being, as in the case of each separate planet, inversely proportional to the square of the distance from him.

Mercury and Venus, being nearer the Sun than ourselves, can never come into apparent opposition to the Sun as seen from the Earth. But they come from time to time into conjunction with the Sun, both on this side when they are said to be in *inferior* conjunction, and beyond the Sun when they are in *superior* conjunction, with him. If one of them, when in inferior conjunction, is near the node of its orbit, where it crosses the plane of the Earth's, the planet will be seen to pass like a round black spot across the Sun, making what is called a transit over his disc. The first time Mercury was ever seen on the Sun's disc was by Gassendi at Paris on Nov. 7, 1631. A transit which occurred on the same day in the year 1677 was well observed by Halley at St. Helena, and this led him to suggest the observation of those of Venus, when they should occur, as the best means of obtaining the distance of the Sun. That planet had already been seen on the Sun by two young Englishmen in Lancashire, Horrox and Crabtree, in the year 1639. No other transit would take place until 1761; it, as well as the following transit in 1769, was (as we have already remarked) extensively observed, and so have since been those of 1874 and 1882. The next pair of transits of Venus will occur in 2004 and 2012. Transits of Mercury take place much more frequently than those of Venus. The last occurred in 1881; two more will take place before the end of this century, viz., in 1891 and 1894.

Mercury can only be seen with the naked eye when near greatest elongation from the Sun (which seldom exceeds 18°), a little before sunrise or after sunset, as the case may be. He is too near the Sun to allow us to make any very accurate observations of his shape, or see anything very distinctly on his surface. His diameter is about 2990 miles; it has been thought that markings on his surface have been seen, indicating that he has a period of rotation on his axis about equal in length to that of our Earth, but this has not been confirmed, and the conclusion therefore remains doubtful. His mass is about one-twelfth that of the Earth, and his density must therefore be a little greater than that of our planet. He revolves round the Sun in about 88 days at a mean distance of about 36 millions of miles, but, as the eccentricity of his orbit is considerable, his actual distance from the Sun varies between 28 and 43 millions.

Venus moves in an orbit more nearly

circular than that of any other of the principal planets, and her distance from the Sun never varies much from 67 millions of miles. She revolves round him in about 225 days. The inclination of her orbit to the Earth's is greater than that of any other except Mercury. Her greatest elongation from the Sun amounts to about 45°, so that she may sometimes be seen for a very considerable part of the night before sunrise or after sunset. In very ancient times she was called, when seen in the morning, Phosphorus, and when seen in the evening, Hesperus. Her phases were first noticed by Galileo in 1610.

The diameter of Venus is about 7660 miles, only a little less than that of the Earth. Her mass is smaller than that of our planet, sufficiently so to make us conclude that her density as well as her size must be somewhat smaller. There are strong indications of the existence of a very considerable atmosphere on Venus; and also that this is so loaded with dense clouds as to render it impossible to observe any permanent markings on her surface, or determine the time of her axial rotation. Some observations of this kind have indeed, as in the case of Mercury, been published, tending to the conclusion that

Venus rotates in about 23^h 21^m; but this conclusion is regarded by astronomers as very doubtful. As Professor Newcomb remarks, "the circumstance that the deduced times of rotation in the cases both of Mercury and Venus differ so little from that of the Earth is somewhat suspicious, because, if the appearance were due to any optical illusion, or imperfection of the telescope, it might repeat itself several days in succession, and thus give rise to the belief that the time of rotation was nearly one day." While, then, we cannot doubt that both these planets have axial rotations, the times in which such rotations take place are not considered to be established.

Mars is a considerably smaller planet than the Earth, his diameter being only about 4500 miles. The ellipticity of his figure is greater than that of the Earth, the difference between his polar and equatorial diameters being about a hundredth part of the latter. His density is less than that of Venus, and only about three-quarters that of the Earth, the mass of which is about nine times that of Mars. He revolves round the Sun in 687 days at the mean distance of about 142 millions of miles.

The disc of this planet is well seen with our telescopes, and many maps have been drawn of the surface, which exhibits in many respects a striking analogy to that of our Earth, differing, however, in this, that on Mars the proportion covered by sea is considerably smaller than that which is dry land. The duration of his axial rotation is now very accurately known, and amounts to $24^h\ 37^m\ 23^s$. The axis is inclined to the orbit at an angle of about 63°, somewhat less than in the case of the Earth, so that the inclination of his equator to the plane of motion is greater by about 3½° than on our planet. Mars is surrounded by an atmosphere which is probably of no great density.

In the month of August, 1877, it was discovered by Prof. Asaph Hall of Washington, that this planet is attended by two very small satellites, to which he afterwards gave the names of Phobos and Deimos respectively. The inner of these (Phobos) is the brightest and probably somewhat the largest of the two: but it is supposed that neither of them exceeds ten miles in diameter. The period of the inner satellite round Mars is only about $7^h\ 39^m$: that of the outer about $30^h\ 18^m$. The distance of Phobos from the centre of Mars is only about 6000 miles, so that its distance from the nearest point of the surface of the planet must be less than 4000 miles, or than the radius of the Earth. Deimos is about two and a half times as far from Mars as Phobos, its distance from the planet being approximately 15,000 miles.

The mean distances of all the small planets from the Sun lie between those of Mars and Jupiter; those of some of them are very little greater than that of Mars, while those of others are not much smaller than that of Jupiter. The actual distance of one (Æthra, No. 132), when in perihelion is smaller than that of Mars when in aphelion. But no small planet ever recedes so far from the Sun as the distance of Jupiter. The one with the smallest mean distance is Medusa, No. 149, for which this is 2·133 in terms of the Earth's mean distance; whilst that of Thule, No. 279, is the greatest, amounting to 4·247 on the same scale. It may be mentioned that the idea (started when only two were known) that the small planets might be fragments of a larger exploded one, has been abandoned since the discovery of so many at such very various mean distances. The whole number of these small bodies now known amounts to 283.

Four were discovered early in this century (the first, Ceres, on the 1st of January, 1801), and these are probably the largest, although it is not likely that the diameter of any one of them exceeds 200 miles.

All the planets which move in orbits exterior to those of the small planets, are much larger than those moving in orbits interior to theirs. Of these, that which is nearest to the Sun is the largest planet of all, Jupiter, sometimes called the giant planet, the bulk of which is about 1300 times as great as that of our globe, his diameter being about 86,000 miles. But his mass being only about 300 times that of the Earth (somewhat less than a thousandth part of that of the Sun), his density must be less than a quarter that of our planet. He revolves round the Sun at a mean distance of about 484 millions of miles in a period amounting to nearly twelve years.

The ellipticity of Jupiter's figure is considerable, and attracts attention the moment it is seen with a moderately large telescope; the compression in fact (or fraction representing the difference between the polar and equatorial diameters divided by the latter) amounts, according to the best measures which have been made of it, to about $\frac{1}{17}$ (that of the Earth is only $\frac{1}{294}$). The planet is surrounded by a thick atmosphere, in which are dense masses of cloud. The belts and spots on the surface are interesting objects of study, but it does not fall within our plan to speak of them in detail here. A large red spot has attracted very special attention during the last few years; it was first noticed in 1878, and has since undergone several remarkable changes in brightness, whilst retaining the same form and size. The motions of the spots have furnished means of obtaining the time of Jupiter's axial rotation with considerable accuracy. It is more rapid than that of any other planet of which the rotation is known, its duration amounting to only about $9^h\ 56^m$. The axis being nearly perpendicular to the plane of the orbit, the equator makes but a very small angle with the latter.

As soon as telescopes were directed to Jupiter, it was seen that he was accompanied by four attendant moons or satellites. Their discovery is generally attributed to Galileo, who noticed them first on January 7, 1610, and gave in his 'Sidereus Nuncius' an account of his subsequent observations, proving them to be satellites. Simon Marius (or rather Mayr) claimed to have discovered them a few weeks before Galileo, but this was contested, and at any rate he did not publish his observations until later. Mayr proposed a name for each satellite, but his proposed names have not been accepted, lest the acceptance should seem to imply recognition of his claim to the first discovery. Galileo named them jointly the Medicean stars, in honour of the Grand Duke of Tuscany, and individually after members of his family, but these designations have been dropped by general consent; for as they were all discovered at the same time, and were called the First, Second, Third, and Fourth Satellite respectively, reckoning according to their distance from Jupiter outwards, this nomenclature has, indeed, been found quite sufficient. Their distances from Jupiter, periods of revolution round him, and approximate diameters are as follows :—

Satellite.	Distance from Jupiter.	Period.	Diameter.
	miles.	d. h. m.	miles.
I.	260,000	1 18 29	2,400
II.	414,000	3 13 18	2,100
III.	660,000	7 4 0	3,400
IV.	1,161,000	16 18 5	2,900

The next largest planet to Jupiter is Saturn, the diameter of which is about 72,000 miles, so that its bulk is rather more than half that of the giant planet, and would contain the Earth's about 750 times. But his density is not much more than half that of Jupiter, and the mass of the latter is equal to between three and four times that of Saturn. Indeed, the mass of Jupiter is more than double that of all the other planets put together, whilst his volume is about one and a half times as great as the aggregate of all the rest. The compression of the figure of Saturn has been determined to be the greatest of that of any planet of which the ellipticity is measurable, and to amount to as much as $\frac{1}{9}$. His period of revolution round the Sun amounts to nearly 30 years; the mean distance from him to about 887 millions of miles.

Belts are to be seen on Saturn similar to those on Jupiter, but they are much fainter on account of the greater distance. Nevertheless, by their aid the axial rotation has been pretty accurately determined to be somewhat slower than that of Jupiter, its period amounting to about $10^{h}\ 15^{m}$. The axis of Saturn makes an angle of about 62° with the plane of its orbit, so that the planet's equator is inclined about 28° to that plane.

There are now known to be eight satellites revolving round Saturn. Owing to the confusion which arose from the order of discovery being different from that of the distances from the planet, it became necessary to give them names, and those proposed by Sir John Herschel have been generally accepted. Counting outwards from Saturn, these are respectively — Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, and Japetus.

Name of Satellite.	Distance from Saturn.	Period.		
	miles.	d.	h.	m.
Mimas	121,000	0	22	37
Enceladus	155,000	1	8	53
Tethys	192,000	1	21	18
Dione	246,000	2	17	41
Rhea	344,000	4	12	25
Titan	797,000	15	22	41
Hyperion	1,008,000	21	7	7
Japetus	2,317,000	79	7	57

The largest of these is Titan ; it was the first discovered, by Huygens, on March 25, 1655. John Dominic Cassini discovered Japetus in 1671, Rhea in 1672, and Tethys and Dione in 1684. No more were discovered until Sir

W. Herschel found the two innermost, Mimas and Enceladus, in the autumn of 1789. Finally, Hyperion, reckoning as seventh in the order of distance, was discovered independently by Bond in America and by Lassell in England in the month of September, 1848. The table above gives their approximate distances from Saturn, and periods of revolution round him. Of their actual sizes, only very rough estimates are possible: Titan is probably about 3200 miles in diameter, Japetus 1800, and Rhea 1200; Mimas is somewhat the largest of the four interior satellities, but each of these, besides Hyperion, is probably less than 1000 miles in diameter.

Saturn is unique amongst the planets in the possession of a ring, or rather system of concentric rings, surrounding it within the orbits of all its satellites. This ring, which has in so many ways been an enigma to astronomers, is now understood to consist in fact of an innumerable multitude of very small satellites, so arranged as to present at a distance the appearance of a thin flat ring, with several narrow divisions in its breadth. When Galileo first saw Saturn with a telescope he was astonished to see what he thought a small body adhering to it on each side, which afterwards disappeared, recalling to mind the old myth about Saturn devouring his own children. Huygens was the first to explain the real nature of the appendage and its varying appearance according to the position of Saturn with regard to the Sun and Earth. This he did in the year 1656 at the end of a pamphlet announcing the discovery of the satellite Titan the year before, which contains a Latin anagram, afterwards interpreted to mean "Annulo cingitur tenui plano, nusquam cohærente, ad eclipticum inclinato." * The explanation is given in his "Systema Saturnium," published in 1659, in which he refers to the observations of William Ball in England † as confirming his own. In 1675 Cassini in France showed that there was a division in the ring. The inner ring of these two is perceptibly brighter than the outer, and it appears that Campani at Rome so early as 1664 had noticed the greater brightness of the interior portion of the ring, though he failed to recognise an actual division between the two parts thus distinguished. Other smaller divisions have been noticed since, particularly one in

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* It is surrounded by a thin plain ring, nowhere adhering to it, and inclined to the ecliptic.

† At Mamhead, near Exeter.

the outer ring by Encke in 1837. But the most remarkable recent discovery in this system of rings is that of what is technically called the dusky ring, inside the two bright rings. This is due to the Bonds of Cambridge, U.S., in 1850, though there are several indications that a shading off of the inner bright ring towards the planet had been noticed long before. Galle had in fact called special attention to it under this description in 1838. Lassell compared the dusky ring to "something like a crape veil covering a part of the sky within the inner ring;" and its transparency was afterwards noticed. Doubtless its peculiar appearance is due to the tiny satellites of which it is composed being much more scattered than those forming the bright rings. It should be mentioned that the outer diameter of the exterior ring amounts to about 166,000 miles; its inner diameter to about 146,000 miles; the outer diameter of the interior bright ring to about 143,000, and its inner diameter to about 110,000 miles. The nearest distance of the innermost satellite from the exterior ring is probably not more than 40,000 miles. The rings and satellites revolve in planes making only small angles with that of the planet's equator.

Beyond the orbit of Saturn, two large planets revolve round the Sun, Uranus and Neptune, the existence of which was not known to the ancients. Uranus was discovered by Sir William Herschel whilst observing at Bath on March 13, 1781, and at first supposed by him to be a slowly-moving comet. Its planetary character was established as soon as the nature of its orbit became approximately known ; and the principal credit of pointing this out is due to Lexell, whose name is more generally known by its connection with the comet of 1770, which he determined to be moving in an orbit of short period, and predicted its return, but it failed to appear on account of getting close to Jupiter and his satellites, thereby undergoing a complete change in the form of its orbit. (See next chapter, p. 60.)

When the planetary character of Uranus was established, Herschel proposed to name it Georgium Sidus, or the Georgian star, in honour of his royal patron, George III. ; others preferred to call it after the discoverer, but when the name Uranus was suggested, it soon obtained general acceptance. This planet takes more than 84 of our years to revolve round the Sun, from which it is distant about

1,784,000,000 of miles. It was seen several times before Herschel's discovery, but always supposed to be a fixed star; the first of these observations was by Flamsteed in 1690. Its diameter is about 32,000 miles.

Some recent observations made by Prof. Schiaparelli at Milan and by Prof. C. A. Young of Princeton, New Jersey, U.S., tend to confirm results obtained by Mädler at Dorpat more than forty years ago (in 1842–3), that this planet has a considerable degree of ellipticity; the compression amounting in fact to about $\frac{1}{12}$, greater than that of any other planet except Saturn. Markings have been noticed on its surface which indicate that Uranus has, like Jupiter and Saturn, a rapid rotation, performed in a period of about ten hours. This rotation, however, takes place in a direction nearly perpendicular to the plane of the planet's orbit.

The density of Uranus is a little less than that of Jupiter, and about 0·23 that of the Earth; its mass is rather less than the twentieth part of that of the giant planet.

About six years after its discovery, or early in 1787, Sir W. Herschel discovered two satellites revolving round Uranus; he afterwards thought he had discovered four more, but the existence of these has not been confirmed. Of course it requires a very powerful telescope to perceive reflected light at so great a distance; and the searches made must be allowed to have proved that no such bodies as these four latter supposed satellites exist, but that some small fixed stars near the planet were taken for such. But two other satellites, additional to Herschel's first two, were discovered by Mr. Lassell towards the end of the year 1851; and on removing his telescope temporarily to Malta the following year in order to profit by its transparent sky, he succeeded in determining their periods with considerable accuracy. These two, which are interior to Herschel's two, were named Ariel and Umbriel; whilst the others received the designations Titania and Oberon.

Name of Satellite.	Period.			Distance from Uranus.
	d.	h.	m.	miles.
Ariel	2	12	29	120,000
Umbriel	4	3	27	170,000
Titania	8	16	57	270,000
Oberon	13	11	7	360,000

It is not possible to measure the sizes of these distant and comparatively small objects; their periods of revolution and approximate distances from Uranus are given above.

The motions of these satellites are nearly perpendicular to the plane of the planet's orbit, and from east to west, or in the reverse direction to that of all known planets, and of the satellites of all the planets which move within the orbit of Uranus.

We now come to Neptune, the most distant known planet of all. When Bouvard was forming his tables of the planetary movements about forty years after the discovery of Uranus, he found that it was impossible to reconcile the observations of that planet since its discovery with the earlier observations made at various times when it was supposed to be a fixed star. He, therefore, in forming his Tables, rejected the latter altogether, and made use only of the former; but stated in doing so that he "left it to future time to determine whether the difficulty arose from inaccuracy in the older observations, or whether it depended on some extraneous and unperceived influence which may have acted on the planet." In a few years the question as the nature of the cause was settled by the way in which Uranus refused to be confined to the course marked out for it by the Tables formed from the observations made between 1781 and 1821. It was evident, therefore, that an extraneous and unknown influence was really acting upon its motion ; nor could it reasonably be doubted that the cause was the perturbing attraction of a planet moving at a greater distance from the Sun, and never (so far as was known) hitherto observed, being probably too faint to be included in any star-catalogues made before that time.

But the problem of calculating the place of an unknown planet by the knowledge only of its influence upon another, staggered the few mathematical astronomers who were capable of attacking it, most of whom were already deeply engaged in labours too essential and exacting to bear an interruption of the length which its solution would probably demand. In 1844–5, however, it was taken up by two young mathematicians, one in England, the other in France, whose names are now famous wherever astronomy is studied. The former, J. C. Adams, is at present one of the Professors of Astronomy at Cambridge, and Director of the Observatory there ; the other, U. J. Le Verrier, was for many years Director of that at Paris, where he died in 1877. We cannot enter here into the history of their investigations. The approximate place of the unknown planet was determined by both; and when found, the actual place was between these two predicted places, but somewhat nearer to that indicated by Le Verrier, who suggested that the planet might be distinguished amongst the fixed stars in the neighbourhood of his calculated place, by its disc. Meanwhile Challis* (then Plumian Professor of Astronomy and Director of the Observatory at Cambridge) had been searching for it by its motion. Believing that the search would probably be long, he mapped down during several weeks all the stars visible in a considerable tract in the heavens around the place indicated by Adams, with the intention of comparing afterwards the places of all these stars and tracing which of them had moved, thus obtaining several approximate places of the planet. But before he had completed his charts in this way, news arrived that Dr. Galle had seen the planet at Berlin, after looking for it in the place pointed out by Le Verrier. Its appearance at once suggested that it was the object of search, besides which it was wanting in a map (then recently made by Bremiker) of the stars in that part of the heavens, which had recently been received at the Berlin Observatory, and the next day (September 24, 1846) the alteration in its place put its planetary character beyond a doubt. Not long afterwards the name Neptune (one of the names suggested for Uranus, when a designation for that planet was under discussion) was by common consent conferred upon this, the most distant known member of the planetary system.

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* Prof. Challis died on the 3rd of December, 1882.

Neptune occupies more than 164 of our years in revolving round the Sun, at a distance somewhat exceeding 2700 millions of miles, about 30 times that of the Earth. The eccentricity of its orbit is the smallest of those of all the principal planets, with the single exception of Venus. In size, it is nearly 1½ times as large as Uranus, its diameter amounting to about 36,000 miles, so that its volume or bulk is very nearly ninety times that of the Earth, but only about a fourteenth part of that of Jupiter. Its density is nearly the same as that of Uranus, and its mass is to that of the Sun in about the proportion of 1 to 19,000. Being at so great a distance, it is not possible to perceive any spots or markings on its surface; so that its time of axial rotation is likely always to remain unknown to us, though we cannot doubt that some such exists, and that, like those of the other large planets, it is probably much more rapid than that of the Earth.

Only one satellite of Neptune is known. This was discovered by the late Mr. Lassell in the month of October, 1846, a very short time after the discovery of the planet itself. Being visible at so great a distance it is probably the largest satellite in the solar system. Like the satellites of Uranus, it moves in a reverse direction to that of the planetary motions, and its orbit is very much inclined to those of the planets (about 55° to that of Neptune itself). Its distance from the centre of Neptune is about 220,000 miles, and its time of revolution round him amounts to 5·877 days or 5^{d} 21 3^{m}. If this planet has other satellites, as is most probable, they must be much smaller, as none has been hitherto detected even with the powerful telescopes which have been brought into use in recent years.

CHAPTER VI.

COMETS.

WHEN Kepler had shown after a laborious investigation of the motions of Mars (extending by analogy the conclusion derived thereby to the other planets), that the planetary orbits are ellipses, and when Newton had proved that this is a necessary consequence of their being attracted towards the Sun (placed in one focus of each ellipse) with a force varying inversely as the square of the distance from him, the theory at once suggested itself that comets might be simply bodies similarly moving round the Sun in ellipses of eccentricity so much greater than those representing the planetary orbits, that they would only be visible in those parts of their elongated orbits which are nearest to the Sun and Earth; the law of equable description of areas, which would of course hold good in their case, causing them whilst in those parts of their courses to move much more rapidly than in any other part, so that the comets would be visible during a small portion only of their whole orbital revolutions. Newton applied these principles to the splendid comet of 1680 (visible a few years before the publication of the first edition of the 'Principia' in 1687), and found that it was moving in an ellipse of so eccentric a character as to approach very nearly in form to a parabola. It was thought by himself and by Halley that it might be identical with great comets recorded as having been seen in the years B.C. 44, A.D. 531, and A.D. 1106, and that the period was about 575 years in length. Subsequent investigations have not confirmed this particular conjecture, but made it probable that the actual period of that remarkable comet (which made such an exceptionally close approach to the Sun) amounts to, not hundreds, but thousands of years, so that any previous appearances most likely took place before historic dates. But in regard to a fine comet which appeared two years later, in 1682, Halley was able not only to calculate the elements of its orbit, but to show that they were almost precisely the same as those of comets observed in 1531 and 1607 ; so far at least, as could be decided by the observations accessible to him of these two. Hence there were in this case good grounds to conclude that all these appearances were of one and the same comet, that its period was about 75 or 76 years in duration, and that it would probably return in the year 1758 or 1759. It did so return, being first seen by Palizsch, at Prohlis, near Dresden, on Christmas Day, 1758; and it has ever since been known by the name of the illustrious astronomer who had so confidently predicted its return. It passed its perihelion at that appearance on March 12, 1759, and, at the next return, on November 16, 1835. Another will be due in the year 1910.

It would take far too much space for us to go into the history of comets generally. We here confine ourselves to narrating a few particulars about this and such others as have been proved to be moving in orbits of the form of ellipses of moderate eccentricity. A very large proportion of the comets which have been observed move in orbits, either parabolic, or elliptic of such great eccentricity as to be undistinguishable from parabolic during the time of visibility.

Of the periodical comets, Halley's is by much the most interesting. Its history has been traced with a very high degree of probability to a date nearly nineteen hundred years ago. In the year B.C. 12, Dion Cassius tells us of a comet seen about the time of the death of the great Roman general Agrippa, and the Chinese annals also mention a comet seen at a date corresponding to this; Dr. Hind has shown that this was probably an appearance of Halley's comet, and the first that can be traced. It is also probably referred to by Josephus as having been seen in the year A.D. 66, when the Jewish rebellion broke out which led to the destruction of Jerusalem by the Roman army under Titus. The Chinese records also speak of a comet seen at that time, as well as of another in A.D. 141, which was probably also the same. In A.D. 218, it appears to have been noticed both in China and Europe, being followed (according to Dion Cassius) by the death of the emperor Opilius Macrinus, soon after his defeat at Irumæ, near Antioch, by Elagabalus. In the years 295 and 373 we are also able to recognise with much probability Halley's comet in accounts furnished by Chinese annalists; and in A.D. 451 it can hardly be doubted that a comet, observed not only in China but also in Europe (about the time of the great defeat of the Huns under Attila at Châlons-on-the-Marne, by Ætius and

Theodoric), was identical with that which bears the name of our distinguished countryman. In A.D. 530 or 531, in the reign of Justinian, "a very large and fearful comet" was seen which (as we have already mentioned) Newton and Halley thought was an appearance of the comet of 1680. The more full observations of the Chinese which have become accessible to us since their time show that it is much more likely that it was a return of the comet of 1682. The appearances in A.D. 608 and 684 are, like some previously noticed, only recorded, so far as is known, in the Chinese annals. But in A.D. 760 a remarkable comet is stated to have been seen not only by their annalists, but by a Byzantine historian in the reign of Constantine Copronymus; Dr. Hind thinks it "little short of a certainty" that this too was a return of Halley's comet. Appearances of it also were probably seen both in Europe and China in the years A.D. 837 and 912: also in A.D. 989, as related in the Chinese records only. The next return was in the year of the Norman Conquest. In the Bayeux tapestry is a representation of some people gazing at a comet which appeared soon after Easter, A.D. 1066, whilst England was threatened with two invasions at once, which both took place in succession, but had very different terminations. This comet also was doubtless Halley's, which was seen again in 1145, 1223, 1301, 1378, and 1456; in the latter year it seems to have been very conspicuous, and to have made a great sensation in Europe, where the Turks, who had taken Constantinople only three years previously, were advancing into Hungary, when they were defeated and repulsed at Belgrade by the famous Hunyadi. The comet was observed at the succeeding return in 1531, but was apparently less brilliant; at any rate, we are dependent for our knowledge of its path on that occasion entirely upon the observations of Peter Apian, or Apianus (the Latinised form of his real name, which was Bienewitz). In 1607 this comet was observed by the illustrious Kepler; and it was, by a comparison of elements deduced from his observations in that year and Apian's in 1531, that Halley was led to the conclusion that both were in fact the same comet as the one observed by himself in 1682.

Such is in brief the history of this highly interesting comet. Two others have periods a very little shorter than that of Halley's, but their history cannot be traced further back than the apparitions preceding the last. One of these was discovered at Marseilles on the 20th of July, 1812, by Pons, the most successful discoverer of comets there has ever been; it became visible for a few days to the naked eye, and passed its perihelion on the 15th of September, the very day on which the conflagration of Moscow broke out, during the French occupation of that city under Napoleon. Its period was afterwards calculated by Encke to be about 70½ years. Rediscovered by Mr. Brooks at Phelps, N. Y., on the 1st of September, 1883, renewed observations showed that the period was slightly longer than as determined by Encke, and that it would arrive at perihelion in the January following, which it did on the 25th of that month. The next return will be due in 1955. The other comet was discovered by Olbers at Bremen on the 6th of March, 1815, passed its perihelion on the 26th of April, and was calculated to have a period of about 72 years. It was re-discovered by Mr. Brooks at Phelps, on the 24th of August, 1887, and passed its perihelion on the 13th of October so that its period is not quite 72½ years.

All other comets of this class have very much shorter periods. That known as Encke's is the most interesting. It was first discovered (by Méchain) in 1786, and again independently (by Caroline Herschel) at Slough, in 1795 and (by Thulis, at Marseilles) in 1805, being each time supposed to be a different body, not hitherto known. Pons was the first to see it in 1818, when he also imagined it was a new comet, but at that return Encke (who always called it Pons's comet) took it in hand, showed that it was moving in an orbit with a period of only about 3⅓ years, that it was identical with those just mentioned, and predicted another return in the spring of 1822. This took place accordingly, and the comet was observed at that and every subsequent return, passing its perihelion on the last occasion on the 28th of June, 1888.

In many respects the next most remarkable of the periodical comets is, or rather was, that known as Biela's, the periodicity of which was detected at its return in 1826, when it was discovered by Biela at Josephstadt in Bohemia. But its first discovery was made in 1772 by Montaigne at Limoges, and it was also independently discovered (being supposed, as in 1826, to be a new comet) by Pons in 1805. The period was determined in 1826 to amount to about 6¾ years, and the comet was accordingly observed again in 1832, in 1845–6, and in 1852. At the second of these appearances it was seen to have separated into two portions, the relative brightness of which fluctuated considerably; the investigations of the late Prof. Hubbard of Washington afterwards showed that this disintegration probably occurred in the autumn of 1844. Both portions returned, but at a somewhat greater distance from each other, in 1852. But since then the comet has not been seen at all, at any rate as a comet, though it is supposed that a shower of meteors seen about the end of November, when the Earth passes through the comet's orbit, may form part of its dispersed material. The connection between comets and meteoric streams is now well established, and we shall allude to it in more detail in the next chapter.

A comet discovered by M. Faye at Paris in November 1843, was found to be moving in a short elliptic orbit with a period of about 7½ years. It has been observed at every subsequent return, the last time in the summer of 1888, the perihelion passage taking place on the 20th of August.

The late Prof. d'Arrest of Copenhagen discovered a small comet at Leipzig in 1851. It was found to be moving in an ellipse with a period of about 6½ years, and was observed again (but only in the southern hemisphere, at the Cape of Good Hope) in the winter of 1857–8. In 1864 it was not seen, being unfavourably placed; it was, however, observed at the returns of 1870 and 1877, but not at the last (when it was calculated that it would pass its perihelion on Jan. 13th, 1884), on which occasion indeed there was felt to be small hope that it would become visible. It will be looked for again in the summer of 1890.

M. Coggia discovered a small comet at Marseilles in November, 1873, which was proved by Prof. E. Weiss to be identical with one discovered by Pons so far back as February, 1818, and to be moving in an elliptic orbit of short period. This probably amounts to about 5½ years, so that nine unobserved returns must have taken place between 1818 and 1873; another was due in 1879, but the comet was not seen either on that occasion or in the winter of 1884–5. The next return will be due in 1890.

Pons discovered another comet at Marseilles in 1819, on the 12th of June, and Encke's investigations showed that it was moving in a short ellipse with a period of about 5½ years. It was not, however, seen again until 1858, when it was re-discovered as a new comet at Bonn by Prof. Winnecke, who, after he had determined its orbit, noticed its identity with the discovery made by Pons nearly forty years previously. Hence it is sometimes called Winnecke's comet, but Pons's seems a juster designation, adding the epithet "short period" to distinguish it from that of 1812. This of 1819 and 1858 was observed again in 1869 and 1875, but not in 1863 or 1880, when its positions were very unfavourable for observation. It was observed at the return which took place in the summer of 1886, passing its perihelion in the month of August; and another return will be due early in 1892.

Brorsen's comet was discovered by him at Kiel in 1846. Its period is also about 5½ years; it was, however, not seen in 1851 or 1863, but was observed in 1857, 1868, 1873, and 1879. At the last return, in the autumn of 1884, it was not seen, being unfavourably placed; the next will be duc in the spring of 1890.

Three comets of short period were discovered at Marseilles and Milan by the late M. Tempel (afterwards Director of the Arcetri Observatory at Florence). The first of these (the period of which is about 6 years) was found by him in 1867; it was observed at the returns in 1873 and 1879, but not at that of 1885, and the next will be due in 1891. His second periodical comet was discovered in 1873; its period is about 5¼ years, and it was also observed in the autumn of 1878, but escaped observation during the subsequent returns towards the end of 1883, and early in the present year (1889). Another will be due in 1894. A comet of short period was also discovered by M. Tempel in November, 1869; but its periodicity was not recognised until after it had been re-discovered by Prof. Swift, Director of the Warner Observatory at Rochester, N.Y., in 1880, in consequence of which it is usual to call it Swift's comet. The period is only about 5½ years in duration, so that an unobserved return must have taken place in 1875. The comet was calculated to be due in perihelion again in the month of May 1886, but, as in 1875, it was unfavourably placed, and escaped observation. Another return will take place in 1891.

Mention should also be made of a comet discovered by Mr. Denning at Bristol on the 4th of October, 1881, which is possibly identical with one discovered by Blanpain at Marseilles on the 28th of November, 1819, and afterwards calculated to be moving in an elliptic orbit, with a period of about 5 years. But if so, this must have been much lengthened by the effects of planetary perturbation, as the period appears to be now nearly 9 years in length, so that the comet may be expected again in the year 1890.

A comet discovered by De Vico at Rome on the 22nd of August, 1844, was calculated to have a period of about 5½ years, and thought to be identical with one observed by La Hire at Paris in 1678, between which and 1844 there would have elapsed thirty times the period calculated for it. It was not seen at the next or at any subsequent return, excepting that Goldschmidt obtained a single observation of a comet at Paris on the 16th of May, 1855, which may have been of this, though its identity cannot be proved.

The above comprise all the comets of very short period which have been known to return. One discovered by E. Pigott in November, 1783, was thought to be moving in an ellipse with a period of about five years; but this was somewhat uncertain, some thinking the period ten years, and, at any rate, the comet does not seem to have been observed either before or since. Mr. Finlay discovered a comet at the Cape of Good Hope on the 26th of September, 1886, which has been calculated to have a period of about 6½ years, so that a return will be due in 1893. But there is a comet of somewhat longer period which has been seen at three returns to perihelion, although the first two of these were not consecutive or nearly so. It is known as Tuttle's, having been discovered by Mr. Tuttle at Cambridge, U.S., in January, 1858, when its periodicity was determined. It was shown that it had in fact been previously discovered by Méchain at Paris in 1790, and that its orbit is an ellipse with a period of about 13¾ years, so that it had returned four times since the first discovery without having been noticed. It was, however, observed in the autumn of 1871, and again in 1885, when it passed its perihelion on the 11th of September. Another return will be due in the summer of 1899.

We have already (in the last chapter) made a passing reference to Lexell's comet of 1770. It was a truly unfortunate body in the way in which its motions were disturbed by the giant planet, Jupiter. In 1767 it approached that body within a distance of only about one sixtieth part of the radius of the orbit of the planet, which subjected it so powerfully to the influence of his attracting mass that the comet's orbit was completely changed. In 1770 it was discovered by Messier on the 14th of June, being at the time very near the Earth, which a few days afterwards it approached within a distance of little more than seven times that of the Moon. Lexell calculated its orbit, and found that it was then moving in an ellipse with a period of about 5½ years. It has, however, never been seen since, and was long known by the name of Lexell's lost comet. Its non-appearance, however, can easily be accounted for. At the return in 1776 its position was such that it was impossible that it should become visible, and before another return, or in the year 1779, it made another approach to Jupiter, much closer even than before, coming indeed nearer to the planet than the distance of its fourth satellite ; this must have so completely changed its orbit again as to render its period afterwards something totally different from what it was before, and from what Lexell's calculations determined it to be in 1770.

There are a few other remarkable comets, surmised to have been seen at more than one return, but not capable at present of being classed as periodical comets, respecting which a few words may be said.

Great similarity has been noticed between the elements (so far as they could be determined from the descriptions given of its course) of the splendid comet of the year 1264, and those of the fine comet observed in 1556, about the time of the abdication of the Emperor Charles V. This was first pointed out by Dunthorne, and attention was afterwards specially called to it by Dr. Hind in his valuable work on "The Comets," and in papers communicated to the Royal Astronomical Society. Hence it was thought extremely probable that these were two consecutive appearances of the same comet, and that we had before us in it the case of one returning after a sojourn of about three hundred years' duration in the depths of space. It was shown that the effect of perturbation would delay another return, and on the whole it was thought most likely that this would take place about the year 1860. Neither then, however, nor at any time since, has the comet put in an appearance. The cause of this is as yet unknown, but it may be remarked that whilst Halley's comet, when in aphelion, is at about the same distance from the Sun as Neptune, a comet with a period of three hundred years would pass far beyond it.

A comet observed by Tycho Brahé and others in 1506, appears to have elements similar to those of the third comet of 1845; and the two may be identical, with a period of about three hundred and forty years.

Allusion must also be made to a great comet, respecting the motions of which there was so much discussion in the autumn of 1882, and the question whether it had any connection with the fine comets of 1843 and 1880, or these with each other, or with any seen in bygone centuries. It is an undoubted fact that the elements of the comets of 1843, 1880, and 1882 are all very similar to each other; and it is probable that those of a comet seen in 1668, which was very imperfectly observed, are also similar. All made, when in perihelion, remarkably close approaches to the Sun, coming within a distance of 700,000 miles of his centre, or about 300,000 miles of his surface. Hence it was suggested that the tremendous attractive force exerted by the Sun upon the comet at so short a distance, might greatly shorten the period at each return, and lead before long to the comet's absorption into the Sun, producing an outburst of solar heat of incalculable amount. On the other hand, similarity of orbit in two or more bodies is no proof of the identity of those bodies, it being quite possible that there may be two or more comets moving along the same orbit at considerable distances from each other. Moreover, the best determinations of the orbit in which the comet of 1882 was actually moving, agree in assigning about 750 years as its period. It is probable, therefore, that all these comets are following each other along the same orbit, which it takes about that period to complete for each; and another member of the same family was discovered on the 18th of January, 1887, which was conspicuous for a few days in the southern hemisphere, but never visible in the northern. It should be remembered, with regard to the comet of 1668, that the observations made of it were so few and so uncertain that it is scarcely possible to draw any decided conclusion from them with regard to its path. The tail only was visible in Europe ; and such knowledge of its orbit as we have is chiefly derived from a map of its course in the heavens, laid down from some very rough observations made in the East Indies, extending over a space of less than a fortnight in the month of March ; from this it appears probable that the comet is moving in the same orbit as those of 1843, 1880, 1882, and 1887.

Of all the periodical comets, that which approaches nearest the Sun is Encke's, which, when in perihelion, is very near the orbit of Mercury (in the year 1835, it made a rather close approach to the planet itself, affording the means of determining a corrected value of its mass), and even in aphelion does not recede so far from the Sun as several of the small planets. With one exception, the other short-period comets attain a distance from the Sun, when greatest, about equal to that of the orbit of Jupiter. Tuttle's, the period of which amounts to somewhat less than 14 years, is near the Earth's orbit when in perihelion, and wanders to a region beyond the orbit of Saturn before reaching aphelion. The distance of Halley's comet from the Sun varies between 0·58 and 35·3 in terms of the Earth's mean distance; that of Venus, expressed in the same way, being 0·72, and of Neptune, 30·05.

It does not come within the scope of this little treatise to speak at all of comets which move in parabolas, or in such elongated ellipses as approach in form to parabolas. Many of these have been computed to move in orbits of which a whole revolution is not completed until after the lapse of several thousands of years; but in such cases the comets are under our observation for so small a proportion of their whole course that its length cannot be determined with great accuracy. The period of revolution of the great comet of 1858 (known as Donati's), amounts to about two thousand years; the splendid comet of 1811 has a period of more than three thousand years; the fine first comet discovered by M. Coggia at Marseilles in 1874* has been computed to be moving in an orbit of more than ten thousand years' period; and a calculation of the orbit of the first comet of 1882 (discovered by Mr. Wells

* He discovered two comets there in that year.

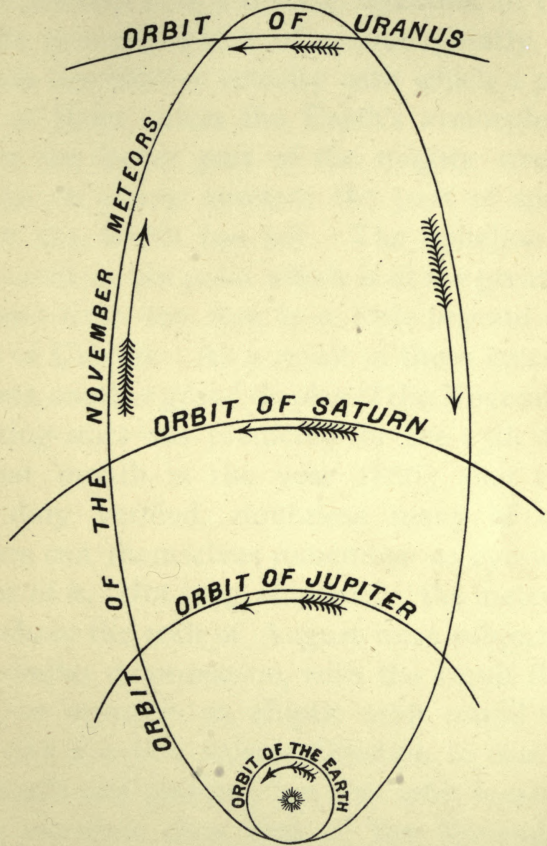
at Boston, U.S., on the 18th of March), assigns about four hundred thousand years as its length of period. As before mentioned, all the comets which have orbits of short period move round the Sun in the same direction as the planets; but many of those (including Halley's) of long elliptic orbits, as well as of those which move in parabolas, have retrograde motion. One which has a period of little more than thirty-three years, and is connected (as will be mentioned in the next chapter) with a stream of meteoroids, moves in a retrograde direction, and is the one of shortest period which does so.

CHAPTER VII.

METEOROIDS.

COMETS, as we have seen, have been for about two hundred years recognised as cosmical bodies moving in many cases in regular orbits round the Sun. That swarms of meteoric bodies to which the designation of meteoroids has been appropriately given, move in a similar manner, has been only known during a quarter of that period, or for about the last fifty years. The first definite establishment of the fact of the existence of such a swarm is principally due to the labours of Prof. H. A. Newton, of Yale College, New Haven, Connecticut, U.S., in the case of the November meteors. The recurrence of the shower as seen in the United States on the 12th November, 1833, the same day as a similar shower had been witnessed by Humboldt and Bonpland in South America thirty-four years before, on the 12th November, 1799, led to a careful examination of previous accounts, and to the discovery that there was evidence that a shower radiates from the same point in the heavens about that time every year (slightly later, by about two days each century) but that it is especially brilliant and conspicuous at the end of each interval of thirty-three or thirty-four years. Several hypotheses were suggested which might account for this; but the investigation of Prof. Adams showed that one and one only of these would explain all the circumstances of the case. This, which is therefore the true explanation, is that the swarm of meteors, of which the November shooting-stars form a portion, moves round the Sun in a regular orbit, with a period of about 33¼ years, and that the perihelion of that orbit, where the meteors are of course nearest to the Sun, very nearly touches the Earth's orbit (see the diagram on the accompanying plate). The Earth, passing through that point of its orbit in the middle of November, meets some meteors on every such occasion; but the meteors being by far more closely aggregated together in a certain portion of their orbit, it is only every thirty-third year that the Earth encounters this portion, called the "gem of the ring." As this extends, however, for some considerable distance along the line of the meteoric orbit (about, in fact, a fifteenth part of its whole length), a fine display, when it does occur, is generally seen on

DIAGRAM ILLUSTRATING THE MOTION OF THE NOVEMBER METEORS.


ORBIT OF URANUS
ORBIT OF THE NOVEMBER METEORS
ORBIT OF SATURN
ORBIT OF JUPITER
ORBIT OF THE EARTH

The Comet discovered on December 19th. 1865 moves in the same orbit; the large arrows show the direction of motion of the Comet and meteors, the small arrows those of the planets.

two or even three years in succession. The orbital motion of the meteoroids, like those of many comets, is in a reverse direction to that of the planets, which of course greatly increases the relative velocity with which a portion of them enters the Earth's atmosphere, whilst the larger part of the mighty stream sweeps on nearly towards the part of space which the Earth has left. The aphelion of their orbit, or the point which is at the greatest distance from the Sun, is a little beyond the orbit of Uranus. As a result of these investigations, another grand display of the November shooting-stars was predicted for the 13th day of that month in the year 1866; that this was duly verified, doubtless many of our readers can themselves remember as eye-witnesses of it. Not long afterwards, the meteors seen about the 10th of August were subjected to a similar examination, with the result that they too move in an elliptic orbit round the Sun, and also in a reverse direction to that of the Earth and planets; but this orbit is much more eccentric than that of the November meteors, and though at perihelion it meets the Earth's orbit, at aphelion it stretches far beyond the orbit of Neptune.

These discoveries were speedily followed by another, the priority in which belongs to Prof. Schiaparelli of Milan. It is that both these meteoric orbits are identical with those of two comets, which, therefore, must be regarded as having some very close and intimate connection with the meteoroids. The orbit of the meteors of November 13th has the same elements as that of a small comet which was discovered by M. Tempel at Marseilles on the 19th of December, 1865, passed its perihelion on the 11th of January, 1866, and was found to have a period of 33¼ years.* And the orbit of the meteors of August 10th coincides with that of the third comet of 1862 (discovered by Professor Swift on the 15th of July, and visible to the naked eye during part of August and September), which has been calculated to revolve round the Sun in a period of about 124 years, although this may be a few years more or less in error. Do comets, then, consist principally of congeries of meteors, which are gradually being scattered or dissipated along the whole extent of their orbits? If so, old reflections on the filmy and "almost spiritual" texture of comets, because stars have been seen nearly through the central parts of some, are quite beside the mark, since there may be large vacuities between the separate meteoric bodies, the aggregate of which forms a particular comet. On the other hand, in many comets there must undoubtedly exist, at any rate at times, a large amount of matter in a state of vapour. The dispersion of the meteoric particles along the cometary or meteoric orbit must be much more complete in the case of the August than in that of the November meteors, since the degree of abundance of the former is far more uniform than that of the latter.

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* A comet is recorded to have been observed by the Chinese in a year corresponding to A.D. 1366, which it is thought was probably moving in the same orbit as this of Tempel's, seen just five hundred years (equal to fifteen of its calculated periods) afterwards.

Another interesting fact, also confirming the above view, must be mentioned. We have already spoken of Biela's comet, and its having ceased to appear at the dates it was expected according to calculation. Now the Earth crosses the orbit of that comet on the 27th of November; and about that time showers of meteors have been seen to radiate from a point in the heavens (in the constellation Andromeda) from which a body moving in the orbit of the comet would seem to approach. A very conspicuous display was seen on that date in the year 1872, when the Earth crossed the comet's orbit about three months after the comet itself should have passed that point, and it was even suspected that a portion of the comet was afterwards seen receding in the opposite direction to that of the radiant point of the meteors ; but this remained somewhat uncertain, as it was difficult to reconcile the motion of that body with the theoretical motion of the comet. Another fine display of meteors was seen on the 27th of November, 1885, when the principal part of the comet was still nearer the Earth than in 1872. There can be little doubt that there is some connection between the meteors and the comet, and the radiant will continue to be watched with great interest.

CHAPTER VIII.

THE FIXED STARS.

HAVING spoken, in the previous chapters, of those bodies, large or small, of which the motions can be traced so as to entitle us to regard them as regular members of the solar system, we shall in this give a short account of what has been ascertained respecting the motions and distances of the far more remote heavenly bodies which come under the general designation of fixed stars, devoting also a few words to the investigations which have been made concerning the probable motion of our own system, as a whole, amongst them.

Those fixed stars which are bright enough to be visible to the naked eye have been watched from the most remote antiquity; and the greater part of the most conspicuous star-groups, or constellations (as they are called), were formed and named in very early times, probably by the Babylonian star-gazers. Until the publication of Bayer's maps (see next chapter) less than three hundred years ago, the only way of indicating any particular star (excepting a few very bright ones which had special names, such as Sirius, Arcturus, &c.) was by its place in the imaginary figure or animal which the constellation containing it was supposed to resemble. Since that time the principal stars have been designated by the letters of the Greek (and when these are exhausted, of the Latin) alphabet, adding the name of the constellation in the genitive case, e. g. α Ursæ Majoris, β Cygni, &c. It should be mentioned that the brightest stars are said to be of the "first" magnitude, the next brightest of the "second," and so on, the faintest stars which are visible to the naked eye being considered to be of the sixth magnitude.

No other knowledge of the fixed stars than that of their comparative brightness and apparent distribution in the sky was or could be obtained before the invention of the telescope, excepting the changes of brightness to which a few are subject, and the occasional and rare appearance of a temporary star never seen before. It is not in all cases easy to say, with regard to some of these, whether the accounts handed down to us really refer to a new star or to a comet. The most ancient record of the appearance of a new star, is respecting that which is said to have burst out in the year B.C. 134, with a brightness sufficient to render it visible in the day-time, attracted the attention of Hipparchus, and led him to draw up a catalogue of stars (the first ever made), with the view of enabling future ages to trace with certainty any subsequent appearances or disappearances. An examination of the Chinese annals shows that the astronomers of that country also noticed this star, which seems to have been situated in the southern hemisphere, and in the constellation Scorpio. They also speak of one which is said to have been seen in the constellation Centaurus in a year corresponding to A.D. 173. Another star is said to have appeared, as bright at one time as the planet Venus, in the year A.D. 389 (in the reign of the Emperor Theodosius) ; but from the accounts given by the ecclesiastical historians, it is evident that a remarkable comet was seen at the time to which this appearance is referred, so there can be little doubt that the report of a new star having appeared is simply due to a misunderstanding of the description of the comet, which moved in the heavens from near the place where Venus then was to the constellation Ursa Major. A similar remark may be made with regard to new stars which are said to have appeared in the northern heavens in A.D. 945 and 1264. They were both, in all probability, comets. We have already referred, in Chapter VI., to the splendid comet of 1264 (the year of the battle of Lewes), which is thought to have been an appearance of the comet seen nearly three hundred years afterwards, in the year 1556. But it is quite certain that a very conspicuous and remarkable new star *did* appear near the constellation Cassiopeia in the year 1572. The celebrated Tycho Brahé made a series of careful observations of this star and left an elaborate account of it in a work devoted to the subject. He first saw it whilst in Germany, on the 11th of November* in that year; its brightness, even then as great as that of Sirius, increased until it surpassed that of Jupiter. The star was for a short time visible in broad daylight, but soon began gradually to fade away, and by March 1574 had totally disappeared, after having been seen, with more or less brilliancy, during a period of about sixteen months. Another temporary star appeared in the right foot of the constellation Ophiuchus in the year 1604, and was observed by Kepler and others. It was at one time as bright as Venus, and continued visible for more than a year, disappearing about the end of 1605. On the 20th of June, 1670, Father Anthelme, a French Carthusian of Dijon, noticed another new star of the third magnitude, very near the head of Cygnus. This star was observed both by Hevelius and by Cassini; it underwent several remarkable changes in amount of brightness during two years, then completely disappeared, and has not since been seen. Another star in the same constellation (now known as 34 Cygni) underwent some remarkable fluctuations of light in the seventeenth century, but has remained unchanged in brightness since, being just visible to the naked eye.

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* It was noticed in other parts of Europe several days before it was seen by Tycho.

Within the last fifty years, several remarkable instances have occurred of stars appearing almost or quite suddenly, of which there is no record of their previous existence. One of these was in the year 1848, when Dr. Hind noticed, on the 28th of April, a star of the fifth magnitude (easily visible to the naked eye), in a part of the constellation Ophiuchus where he was certain that, so recently as the 5th of that month, no star so bright as the ninth magnitude was visible; nor is there any record of a star having been observed there at any previous time. From the date of its discovery it began continuously to diminish in brightness, and it is now visible only through a very powerful telescope. A still more remarkable, as well as more recent case of the appearance of a temporary star (temporary at least as regards its visibility to the naked eye), is that of a star in the constellation Corona Borealis, which seems to have burst out quite suddenly on the 12th of May, 1866, when it was first noticed by the late Mr. Birmingham of Millbrook, near Tuam, Ireland. It was at the time of discovery of the second magnitude, but diminished so rapidly as to be invisible to the naked eye by the end of the month. In the autumn of the same year it increased somewhat in brightness again, but not sufficiently to become visible without a telescope; and afterwards sank down to what must be considered its normal or natural brightness. A third instance of the kind occurred in 1876, when the late Dr. Julius Schmidt* noticed on the 24th of November a new star, of the third magnitude, in the constellation Cygnus, which afterwards gradually faded away, ceasing to be visible to the naked eye in about a month, and is now only to be seen with the aid of a very powerful telescope. The most recent case is that which took place towards the end of the month of August, 1885, in the midst of the great nebula in Andromeda; but the star never became bright enough to be visible to the naked eye.

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* Formerly Director of the Observatory at Athens, where he died in February, 1884.

Astronomers now regard the appearance or disappearance of a star simply as amounting to an increase of its brightness sufficient to render it visible when previously out of the reach of our vision; or, on the other hand, to a diminution of brightness sufficient to render one which was visible no longer so, either to the naked eye or possibly even to the telescopic power applied to it. The expression, variable stars, is therefore now considered to be applicable to all such stars. The number of those which may be called regularly variable, being subject to regular changes in brightness of various degrees, is at present known to be very large, and is frequently being increased by fresh discoveries (these being usually of stars subject to smaller mutations of brightness); and there are also a few stars which undergo some remarkable irregularities of change of this kind. The two most interesting cases of the latter class are those of the stars called *o* Ceti and η Argûs. The former, sometimes called Mira Ceti, was first noticed as being subject to change in 1596, by Fabricius, who saw it of the third magnitude in August, and perceived in October that it had ceased to be visible. Bayer saw it in 1603, and Phocylides in 1638, the latter noticing (which Bayer did not) that it was the same star, thus shown to be subject to variability of brightness. The observations of Hevelius between 1648 and 1662 established its period, which is about 331 days in length; but (as we have said) the changes of brightness in this period are themselves of a very variable kind, neither is the period quite constant in length. The star is usually visible to the naked eye for about six months of its period, and invisible during the remaining five months.

Halley was the first to suspect changes of brightness in that remarkable star in the southern hemisphere, η Argûs, which he had observed at St. Helena in 1677 as of the fourth magnitude. Lacaille in 1751 saw it of the second; and its changes from time to time since have been exceedingly irregular. In 1838, and again in 1843, it surpassed for a while all other stars in brightness, excepting only Sirius. After the latter date, it slowly but steadily diminished, and ceased to be visible to the naked eye in 1867.

Of the variable stars of short period, the most remarkable is that known as Algol or β Persei. Its usual magnitude is about the second, and as such it shines constantly and regularly for a period of about two days and a half; then it fades gradually almost down to the fourth magnitude, afterwards recovering its ordinary brightness by a similar gradual increase, the whole amount of change taking place in about nine hours, so that the complete length of a period is not quite three days; more accurately, $2^{d}\ 20^{h}\ 49^{m}$. The most obvious and probable explanation is the regular interposition of an opaque body revolving round Algol, and cutting off at each revolution a portion of its light in the manner of a partial eclipse.

The above are the most conspicuous and easily-detected changes of brightness in the fixed stars, but about one hundred and fifty stars are now known to be variable, and the application of photometry as an accurate means of measuring the amount of light of a star, will probably considerably increase this number. In many cases, the variability is confined within narrow limits; in others the stars, even when at their greatest brightness, are scarcely, or not at all, visible to the naked eye. But it is not within our plan to describe or even enumerate these phenomena.

The next point on which something is to be said is that of the attempts which have been made to determine the parallaxes, and thereby the distances, of some of the fixed stars. This is a problem which completely baffled astronomers until less than fifty years ago. For so vast is the distance of even the nearest fixed star, that although we use the diameter of the Earth's orbit as a base, by comparing observations made at opposite parts of the year, nevertheless, the angle formed by it at the star (the half of which is the star's annual or heliocentric parallax) is so exceedingly small, as to be scarcely distinguishable from inevitable errors of observation. Early in the present century Brinkley thought from his observations at Dublin that he had found parallaxes amounting to 2″ or 3″ for several of the brighter stars; but Pond (who succeeded Maskelyne as Astronomer Royal in 1811) showed by more accurate Greenwich observations that these conclusions were untenable. The first really satisfactory determination was made long afterwards by Bessel in the case of a star only just visible to the naked eye, known as 61 Cygni. Attention was directed to it as being probably much nearer us than others, in consequence of its unusually large proper motion in the heavens, which carries it through an arc of about 5″ in the celestial sphere every year. Taking advantage of the circumstance that there are two other small stars (61 Cygni is itself double) in its close neighbourhood, which, not sharing in this motion, are probably much farther off, Bessel commenced, in 1837, a series of observations of this star at Königsberg with the view of determining its parallax relatively to that of the small neighbouring stars; as their parallax might fairly be considered insensible, the result would practically be the value of the parallax of 61 Cygni, or of the two stars composing it. In the year 1840 he was able to announce that this quantity was thus in fact measurable, and amounted to about 0″·35. Later observations by other astronomers have essentially confirmed this, the latest and probably the most accurate (that of Prof. Asaph Hall of Washington) making it somewhat smaller, so that the true value is probably about 0″·3. The resulting distance of 61 Cygni from the solar system is nearly 70 billions of miles. Meanwhile, several series of observations (commencing with those of Henderson, made about the same time as Bessel's of 61 Cygni) of a bright star in the southern hemisphere, *α* Centauri, have proved that its parallax is probably the greatest of all the fixed stars ; some measures indeed make this nearly equal to a second of space, but the best determination appears to be that recently made by Dr. Gill at the Cape of Good Hope, which amounts to 0″·75, indicating a distance of somewhat less than 30 billions of miles. Several other stellar parallaxes have since been measured with more or less satisfactoriness. Those of Sirius and Capella are about 0″·4 and 0″·3 respectively ; one small star in Lalande's catalogue (No. 21,185) has yielded a parallax of about 0″·5, and that of another (No. 21,258) has been found to be about 0″·3. Several have been determined of smaller amounts than these, to which we shall not further refer.

In speaking of 61 Cygni, we used the expression double star ; we must now distinguish the two classes of stars which come under that designation. A star which appears like a single star to the naked eye, but when viewed with a telescope is seen to consist of two so near as not to be separated by the unaided vision, is naturally called a double star. But the fact of there being two stars in such close proximity does not of itself prove that there is any connection between them. They may be merely optically double, that is, only appearing double because the individual stars are situated nearly in the same line of sight. But Sir William Herschel's persevering surveys of the heavens revealed to him so large a number of these apparently double stars, that the probability * appeared great that in many cases there must be some physical connection between the separate stars composing them. In the year 1782 he commenced the practice of carefully observing and recording the relative positions and distances of the stars which he had noticed as being apparently closely double. When these values were determined again, after an interval of some years, it clearly resulted that in many cases the components of a double star have a distinct motion with reference to each other.

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* This had been suggested several years before as likely by Mitchell ('Philosophical Transactions' for 1767).

To these, then, the name of binary stars has been given, to distinguish them from such as are only optically double ; and as time has gone on, and a constantly larger number of observations has been made and compared, more and more of the latter have come under the former category. Sir William Herschel's first paper on the subject is contained in the *Philosophical Transactions* for 1803, in which he remarks that the series of observations, of which he there gives an account, is distributed over a period of twenty-five years, and proves that many of the stars whose mutual positions and distances had been measured by him, "are not merely double in appearance, but must be allowed to be real binary combinations of two stars, intimately held together by the bond of mutual attraction." One of the first to follow up this subject (the high interest attaching to which has led many skilful astronomers to devote much attention to it in recent years) was the elder Struve ; a catalogue containing the results of his observations (made at Dorpat and Pulkowa) of no fewer than 3134 double stars was published at St. Petersburg in 1837. The relative motion of many of the binary stars has been proved to be of the nature of a regular orbital revolution of one of the components round the other. Among these, the most interesting cases are those of ζ Herculis, ξ Ursæ Majoris, and 70 Ophiuchi, in which the periods of revolution have been determined with very considerable accuracy to amount to about 34, 61, and 94 years respectively. The shortest is that of δ Equulei, which Mr. Burnham from his observations with the great 18½ inch telescope at Chicago has recently found to be less than eleven years. Much longer than any of these, and therefore somewhat less certain, are the periods of revolution which have been calculated for those interesting and long-known double stars, γ Virginis, γ Leonis, and Castor. The first of these amounts to about 180, the second to about 400, and the third to nearly if not quite 1000 years. Accurate and long-continued observations of the proper motions of the larger stars which are regularly made at observatories have disclosed, by means of the irregularities of these motions, more than one instance of the disturbance of a star by an unseen companion, so that the fact of the star being binary was only discovered by this means. Such was the case with the brightest of all the fixed stars, Sirius; but the disturbing companion was afterwards detected as a small star near it, visible only with a powerful telescope. But Procyon, the principal star in Canis Minor, is also subject to a similar irregularity of proper motion; and one which would seem to result from the fact of its moving in an orbit round a companion either opaque or possessing too feeble a luminosity to be within our perception by the best optical means at present available; the period of revolution in this case amounts to about 40 years.

Nearly all the stars, when observations of them made at considerable intervals of time are compared together, are found to be endowed with regular though slow changes of place in the heavens, which are called their proper motions. We shall consider presently whether the whole of these are in all cases due to actual motion of the stars in space; but certainly a considerable part of the proper motions which are exceptionally large must be so. It has already been mentioned that attention was directed to 61 Cygni as being probably nearer us than most of the fixed stars, by the circumstance of its having a very large proper motion, amounting to about 5″ in a year. Two small stars, one in the northern, the other in the southern hemisphere, having no designation but numbers in star catalogues (1830 and 9352 in those of Groombridge and Lacaille respectively), have proper motions even larger than this, being each 7″ in amount, or nearly so; but these stars do not appear, like 61 Cygni, to be much nearer the solar system than others. Several stars have proper motions somewhat less than these, each amounting to between 4″ and 5″, but those of the great mass of stars are much smaller, and only to be recognised by comparing different observations made with great precision, and separated by considerable intervals of time. From a discussion of several of the best determined of these, Sir William Herschel considered that they were in part produced by a movement of our sun and solar system in space among the stars; and he indicated a point in the heavens in the constellation Hercules as that towards which this movement is carrying us. Subsequent investigations on this subject have been made by other astronomers; one of the latest being that of Sir George Airy* in 1859, applied at first to about 300 stars, and afterwards extended by Mr. Dunkin to 1167 stars, 819 of which are in the northern and 348 in the southern hemisphere. All these investigations agree to the extent of placing the apex of the solar motion in the constellation Hercules, and therefore not far from the point first indicated by Sir W. Herschel in 1783. Theories have been formed with regard to a central point round which the solar motion has been thought to be performed; and the late Prof. Mädler of Dorpat, founding his conclusion also on a comparison of a number of stellar proper motions, considered that he had shown that this was round a point in the heavens situated in or near the cluster of stars (see next paragraph) known as the Pleiades. To this theory, the name of the "central sun hypothesis" has been given; but Mädler protested that he had never suggested that there was a central sun or other body in the place round which the observations indicated, as he thought, that our sun and system were moving. His theory has not met with general acceptance amongst astronomers, and it is felt that such speculations are at least premature, and that a larger number of proper motions than are as yet available, resulting from observations extending over very long intervals of time, must be compared and discussed before such a problem can be attacked with any reasonable prospect of success.

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* Astronomer Royal from October 1835 until August 1881, when he resigned, and was succeeded by Mr. Christie.

Something will perhaps be expected here concerning star-clusters and nebulæ; but it does not come within our scope to say more than a very few words. Casual inspection of the heavens shows that whilst many of the fixed stars are arranged in groups or constellations which imagination has likened to the forms of animals and other objects (some of these in strings of various twists suggesting the idea of serpents or dragons), and that these groups are spread out over regions of the sky of many degrees in extent, in certain places a group of stars is seen arranged close (sometimes very close) to each other, so as to form a sort of cluster. The most remarkable of these clusters is that called the Pleiades, in the constellation Taurus; every eye can perceive six stars in this, some persons with unusually acute vision can detect several more,* and with a moderately good telescope at least a hundred become visible, whilst the most powerful reveal the existence of more than a thousand. Near this, in the same constellation, is a more scattered group called the Hyades, resembling a letter V; and another in the constellation Cancer, called Præsepe, is visible to the naked eye, but not as a cluster of stars, which the telescope shows it to be; without such aid it looks like a dullish spot or nebula in the sky, not well seen unless the night be very clear. The telescope, whilst it shows this and many other nebulous or cloudy-looking masses to be composed of very distant or very minute stars, brings into view many more not visible to the naked eye at all. The most remarkable of all the nebulæ is that in the constellation Orion, in the part of it called "the sword," and near the star θ Orionis. It is not visible to the naked eye, and appears to have been first seen by Cysat, a Swiss astronomer, in the year 1618. Although this gigantic object contains a large number of telescopic stars, yet the spectral analysis of its light has shown that a portion of the light which we receive from it and from some other nebulæ is due to glowing gas.

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* Hyginus and Ovid say there are only six; but it is in evidence that as many as thirteen were seen before the invention of the telescope.

Across the sky in clear nights there is seen to stretch a band or zone of luminous matter, which was a great enigma to the ancients and received the name of the Galaxy, or Milky Way. As soon as a telescope was applied to the heavens, it was seen that this appearance was produced by millions of stars apparently scattered like dust along the black ground of the sky. Analogy led many to suppose that the nebulæ or smaller patches of luminous matter which were brought into view by telescopes were also masses of stars, resembling, on account of their greater distances, portions of the Milky Way as seen by the naked eye. And, indeed, many of these were "resolved," as it is called, into stars by the application to them of more powerful telescopes. But (as we have just stated with regard to the great nebula in Orion) it is now known that it is not the case with all, or, at any rate, with the whole of the matter of which they consist. This knowledge is a comparatively recent discovery, obtained by means of the analysis of their light by a spectroscope, as we have not space here to describe. But the improbability of the older view had been shown by Sir John Herschel's observations of those remarkable celestial objects in the southern hemisphere which, from having been first noticed by Magelhaens in the earliest voyage ever made to the Pacific Ocean, are called the Magellanic clouds. These consist of two large roundish nebulous masses of light, one larger than the other, which are conspicuous to the naked eye, and look not unlike portions of the Milky Way. The larger remains visible even in strong moonlight, which obliterates the smaller. When viewed through powerful telescopes these objects are seen to contain multitudes of stars and hundreds of nebulæ which cannot be resolved into stars, all wedged together in such a way as to suggest some close and immediate connection between them inconsistent with the idea that portions are at very much greater distances from us than other portions.

CHAPTER IX.

THE CONSTELLATIONS.

THE distribution of the stars visible in the northern hemisphere into groups, or (as they usually called) constellations, was made in very ancient times. Several less important or conspicuous groups have been added since ; and the principal constellations near the South Pole, visible only in the southern hemisphere, were formed and named by the navigators of the sixteenth century, especially Pierre Dircksz Keyser (sometimes called Petrus Theodori), chief pilot of a Dutch fleet which sailed to the East Indies in 1595, others being added by Lacaille when making his observations at the Cape of Good Hope about the middle of the last century.

A considerable number of bright stars have special names, which were given them by Greek and Arabian astronomers or stargazers ; but with these exceptions, the only way of referring to any particular star, until comparatively modern times, was by means of its place in the imaginary figure or animal which the constellation containing it was supposed to resemble, *e. g.*, the star in the head of Andromeda, in the tip of the tail of Ursa Major, &c. The suggestion to designate each star by the letters of the alphabet placed before the name of the constellation was first made by Alexander Piccolomini, an Italian ecclesiastic and amateur astronomer, who published at Venice in the year 1559 a small work on the fixed stars, in which he gave some rough diagrams of the principal constellations, with Latin letters affixed to the most conspicuous stars in each. The suggestion, however, was not generally adopted until John Bayer, of Augsburg, published in 1603 his well-known series of maps of the constellations, in which he designated each star therein marked by one of the letters of the Greek alphabet; and these have been universally accepted for use, Latin letters being used when the Greek alphabet is exhausted. Numbers also (following the list in Flamsteed's catalogue) are employed in the same manner, taken in the order of the right ascension of the stars in each constellation; these are used exclusively for the fainter stars which have no letters, and in addition to them for the brighter stars which have. It should be noticed that in lettering the principal stars, Bayer did not (as some have supposed) make the sequence of the letters follow throughout the order of apparent brightness. The stars in each constellation were taken as following the old division into orders or classes of magnitude, and excepting that the brightest star in each was called α of that constellation, the letters given to the stars in each class were arranged rather according to the form of the figure represented, than the alphabetical succession of the letters. This is very clearly to be seen in the seven principal stars of Ursa Major, all which are reckoned to be of the second magnitude. The brightest is as usual called α; this star together with β form the "pointers," or two stars pointing towards the pole-star; γ, δ, are the two other stars of the so-called "wain," and ϵ, ζ, η, are the three in the tail of the bear, or the three horses of the imaginary chariot; all persons, however, must have noticed that of these seven stars, δ is considerably the faintest, although taken like the others as of the second class of magnitude. It should also be mentioned, that from one of the figures occasionally touching or overlapping another, the same star has sometimes, in Bayer's original nomenclature, a name by a different letter in two constellations; thus, β Tauri is the same star as γ Aurigæ, α Andromedæ is identical with δ Pegasi, &c. To avoid confusion, astronomers have dropped the secondary and retained only the primary designation in each case.

Letters were affixed to the stars of the constellations which are only visible in the southern hemisphere by Lacaille, who made the order of the letters correspond in most cases more nearly with the successive gradations of brightness of the stars than Bayer had done with the great mass of the constellations lettered by him.

It is not our intention here to give a description of all the constellations; this must be sought in large works on astronomy, or in such as are exclusively devoted to this purpose, for which many maps are requisite. But a few remarks may be made with reference to some of the most remarkable stars and groups, and especially to the constellations in and around the zodiac.

The plane of the Earth's equator extended to the heavens, traces out a circle called the celestial equator or equinoctial, everywhere of course distant 90° from either of the celestial poles, the northern of which is indicated in the sky by a star of the third magnitude very near it, called from this circumstance Stella Polaris, the Polar Star, or more commonly, the Pole-Star. The similar prolongation of the plane of the Earth's orbit to the heavens, traces out a circle inclined to the equinoctial, which is called the ecliptic. The angle of inclination of this to the former circle is 23° 28′, the same at which the Earth's equator is inclined to its orbit; and the two circles intersect each other at two points called the equinoxes or equinoctial points. A zone or band extending 8° on each side of the ecliptic is called the zodiac; within this the apparent positions of the Moon and all the large planets in the sky are always situated, as the inclinations of all their orbits to that of the Earth are less than 8°. The stars distributed along and around this zone are distributed into twelve constellations, Aries, Taurus, Gemini, Cancer, Leo; Virgo, Libra, Scorpio, Sagittarius, Capricornus, Aquarius, Pisces; and the line of the ecliptic itself is divided into twelve signs (as they are called), each taking its name from the constellation nearest to it. At the time of the earliest astronomical writings, the equinoctial points were in the constellations Aries and Libra; and they are still said to be in the "first" or initial "points" of these signs, although in consequence of the precession of the equinoxes,* they are now in the constellations Pisces and Virgo, and in two thousand years more will be in Aquarius and Leo respectively.

It is evident from the above that six constellations of the zodiac, Pisces, Aries, Taurus, Gemini, Cancer, and Leo, occupy a more northern position in the heavens than the other six, Virgo, Libra, Scorpio, Sagittarius, Capricornus, and Aquarius; so that the former are more often visible in the northern hemisphere than the latter. The following considerations will show when these constellations are above the horizon at night. The place of the Sun in the heavens is, of course, always in the celestial ecliptic, and therefore within the zodiac, though his light prevents the stars around him, or any other stars (excepting a few of the brightest when not too near him, which may be seen through a good telescope, or during a solar eclipse), from being visible during the day. He is in the vernal equinox (so called from its being the one passed by the Sun in the spring) on the 20th of March; but, as previously mentioned, whilst that point is still called (as in ancient times) the first point of the sign Aries, it is really now in the beginning of the constellation Pisces. The Sun is therefore at the beginning of the group called Aries towards the end of April, and in the middle of it in May. It follows that the constellation at the opposite side of the zodiac, which is called Libra, will at that time be on the meridian, or due south at midnight, and the rest in order, so that the annexed table will give the zodiacal constellations which will then be nearly in that position at the commencement of the successive months of the year :—

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* This consists of a rotatory motion of one circle round the other, produced by the gyratory movement of the Earth's axis (see p. 3), in consequence of which their points of intersection move slowly forwards, completing a whole round in about 25,800 years.

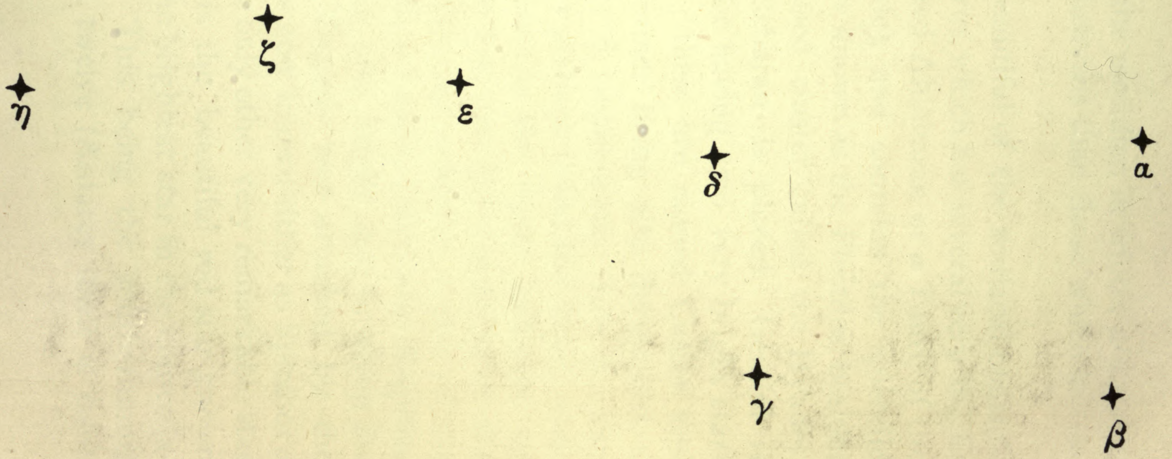
January	Gemini.	July	Sagittarius.
February	Cancer.	August	Capricornus.
March	Leo.	September	Aquarius.
April	Virgo.	October	Pisces.
May	Libra.	November	Aries.
June	Scorpio.	December	Taurus.

Before midnight each of these constellations will be to the east, and after it to the west, of the meridian in the month against which it is here placed. Those portions of the zodiac which are on the meridian in winter are much higher in the heavens than those which are on it in summer.

The most beautiful of the zodiacal constellations is Taurus, which has several very bright stars (one called Aldebaran or *α* Tauri, of the first magnitude), and contains the splendid cluster of stars known as the Pleiades, besides the more diffused cluster called the Hyades, in which Aldebaran is placed. Gemini is remarkable for having two very bright stars near together ; these are named Castor and Pollux, the former being also designated *α*, and the latter *β*, Geminorum. Leo is a fine group, and has perhaps (what few have) some little resemblance to the figure indicated by the name ; the fore part has something of the shape of a sickle, and contains a star of the first magnitude, *α* Leonis, called also Regulus. Virgo has only one bright star, to which the name Spica Virginis was attached by the ancients ; it is now known either as Spica or *α* Virginis. The only other very remarkable star in the zodiac is the beautiful red star known as Antares, the brightest star in the constellation Scorpio. This being the southernmost group of the twelve (Antares itself is more

To face p. 103.

DIAGRAM ILLUSTRATING THE RELATIVE POSITIONS OF THE SEVEN PRINCIPAL STARS OF URSA MAJOR



than 26° south of the equator), it is very low in the heavens when visible in England, which is (as will be seen from the table) in the height of summer.

With regard to the other constellations, a few words must suffice. The most splendid is that known as Orion, which is partly in the northern and partly in the southern hemisphere. The three bright stars in a straight line above the middle of it (commonly called Orion's belt, but by astronomers δ, ϵ, ζ, Orionis), point in an easterly direction nearly towards Sirius, the principal star of Canis Major, which is the brightest star of all in both hemispheres. Of the stars near the north pole, the seven which form part of Ursa Major are best known. The map on the accompanying plate shows the relative positions of these stars. As already mentioned (p. 97), a line prolonged through β and α points towards the pole-star. Another (carried to a considerably greater distance) through ζ, η, passes nearly through Arcturus, the principal star in the constellation Boötes; and one carried in the reverse direction through δ, α, will similarly indicate the position of Capella, the principal star in Auriga, and the brightest in the northern hemisphere.* On the opposite side of the pole-star from Ursa Major, and at about an equal distance from it is the fine group called Cassiopeia, which contains several bright stars arranged somewhat in the shape of an irregular W. Next to Capella, the brightest star in the northern hemisphere is Vega, the principal star of the small constellation Lyra, which in the latitude of London is at very nearly the same distance from the pole as the horizon, so that in the lowest part of its diurnal course it approaches very close to the horizon, but never actually sets below it. To the west of Lyra, is the large and scattered group known as Hercules; to the east of it, the constellation called Aquila, the three most conspicuous stars in which are very near together, and almost in a straight line, the brightest of the three, *a* Aquilæ, being in the middle. Beyond Cassiopeia from the pole-star is the constellation Andromeda, the three principal stars in which form, with the three brightest stars in Pegasus at one end and the largest star in Perseus at the other, a configuration resembling the seven principal stars of Ursa Major. That star in Andromeda (*α*) which is nearest to Pegasus, was regarded by the ancients, and marked by Bayer (see p. 98), as belonging to both constellations; the square formed by it and *α*, *β*, *γ* Pegasi is called the square of Pegasus.* Nearly between Aquila and Pegasus is the constellation Cygnus, which resembles a Latin cross; whilst between Aquila and the southern part of Hercules is the northern part of Ophiuchus, a constellation extending into both hemispheres.

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* It is thought that this star has somewhat increased in brightness of late years, and that Vega was formerly the brightest.

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* The following shows the respective positions of the four stars in the square:—

α Andromedæ.	β Pegasi.
γ Pegasi.	α Pegasi.

CHAPTER X.

THE REFRACTION, PROPAGATION, AND ABERRATION OF LIGHT.

IN a work on astronomy, however small, it seems essential to make some reference to the means by which the heavenly bodies are brought to our sight through the agency of light, and the effects of this upon their apparent places. We do not propose to enter into an explanation of the composition of light, or of the nature of the undulations by which it is propagated, which would be appropriate only in a treatise on optics. The undulations or waves are transmitted through a very rare medium diffused through all space, to which the name of ether has been given ; it is called luminiferous (*i.e.* light-bearing) ether to distinguish it from the chemical substance known also as ether. The vibratory motions of the particles of this ether, which are called waves of light, when once originated by a luminous body acting as a source of light, are transmitted through the atmosphere in its ordinary state, when it is permeated by these particles, and through other substances called for this reason transparent. In passing from one transparent medium into another of different density, the rays of light, propagated originally in straight lines, are bent or turned in a direction inclined to that previously followed; this bending is called refraction, and is greater, the greater is the difference of density of the different media through which the light is successively transmitted. It also varies according to the angle of inclination to the surface of a medium at which a ray of light enters it; the law being that if the media be the same, the sine of the angle of incidence (whatever that angle be) is always in a constant ratio to that of the angle of refraction. This law was first discovered by Willebrord Snell, of Leyden, about the year 1621. The ratio in any particular case can only be determined by experiment. When rays of light come to us from one of the heavenly bodies, they suffer a constantly increasing refraction as they pass through the successive strata of the Earth's atmosphere, which are more and more dense the nearer they are to the Earth itself. The general result can only be ascertained by astronomical observations, the celestial object appearing in the direction in which the ray of light by which we see it finally reaches the eye. The law just mentioned shows that a body exactly overhead, or in the zenith of any place, is seen in its true position, or by rays which have undergone no refraction at all; and that the refraction is greater the farther the object is from the zenith, or the nearer it is to the horizon. Half-way between the two, or at an altitude of 45°, the refraction amounts to about 1′; at 20° to 2½′; at 10° to 5¼′; at 5° to 10′; close to the horizon it is as much as 33′ or 34′, varying according to the state of the atmosphere. As this is a little more than the apparent diameter of the Sun or Moon, it follows that when either of those bodies seems to be just above the horizon, it is really just below it; the effect of refraction being always to make a heavenly body appear higher above the horizon than it really is.

That the propagation of light, whether it be a substance as was formerly supposed, or an undulatory motion in a substance as it is now known to be, should occupy time, seems *à priori* what might be expected. But so extremely rapid is its propagation, that the ancients, having no means of recognising it by astronomical observations, appear to have thought that it was instantaneous, which it practically is between distances on the Earth's surface. The first person to discover that the velocity of its transmission is measurable was the illustrious Ole (commonly called Olaus) Römer of Copenhagen in 1675, whilst discussing the observations of Jupiter's first satellite made by himself and by Cassini at Paris. He found that the intervals of time between successive immersions of the satellite into the shadow of the planet and its emersions therefrom were different according to whether the Earth in its orbital motion was approaching Jupiter or receding from it; and he concluded that the cause of this was the Earth's motion combined with that of light, which was thus recognised to be a sensible and measurable quantity. Cassini contested this explanation proposed by Römer of the differences observed, but it nevertheless gradually obtained general acceptance amongst astronomers, and about fifty years after its publication a most remarkable confirmation of its truth was obtained by the discovery of the aberration of light, to be described presently.

We do not propose here to enter upon the different values of the velocity of light which have been subsequently determined by different methods. Suffice it that the best determinations made by the refined and accurate observations of modern times make it about 186,300 miles a second. It takes light, therefore, about $8^m\ 19^s$ to reach us from the Sun when at its mean distance ;* and when we are observing Neptune, the most distant planet of our system, we see it by light which has left it somewhat more than four hours previously. This will enable us to express the distances of some even of the enormously distant fixed stars by small figures. It has become customary to call a light-year the distance which light will travel in a year ; this amounts to nearly seven billions of miles. The nearest fixed star (α Centauri, so far as is known) is, as stated in Chapter VIII., nearly thirty billions of miles distant from us, which corresponds to about four and a half light-years—light taking about that length of time in reaching us from the star in question. In like manner, light is considered to be about six years in reaching us from 61 Cygni.

A few words in conclusion on the aberration of light. Dr. Bradley, whilst making, first at Kew in 1725, and afterwards at Wanstead in

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* Römer's original determination (of course only approximate) was that it was between eight and nine minutes.

1727, a number of careful observations of γ Draconis (a star which crosses the meridian in the south of England very near the zenith), in the hope of being able to determine its parallax and distance, was surprised to notice a regular change in its apparent position, of which the period was (like that produced by a measurable parallax would be) exactly a year, but the direction was the reverse of that which would be caused by parallax. Speculating on the source of this, it occurred to him that the change of place of the observer produced by the Earth's motion would, combined with the gradual propagation of light as discovered by Römer, lead to an effect of this kind. Calculation confirmed this conjecture, and the observed amount of the aberration of light (as this phenomenon is called) is one of the methods by which the velocity of light has been subsequently determined. The nature of the apparent change in a star's place produced by aberration will depend upon its position with respect to the plane of the ecliptic. For if that position be in the plane of the Earth's orbit, the star will in consequence only appear to change its place in a straight line (or rather an arc of a great circle in the celestial sphere); if it be nearly in the pole of the ecliptic, the apparent place will describe a circle round the true place; whilst if situated anywhere between these positions, the change of apparent place will be an ellipse of which the eccentricity is greater the nearer the position is to the plane of the ecliptic. The angular semi-diameter of the circle in the former case, or the semi-major axis of the ellipse in the latter case, is of course practically a constant quantity, since the only circumstance that can cause a variation in it is the change of velocity of the Earth in its orbit at its different distances from the Sun, the proportion of which to the whole velocity is very small. This constant quantity is called the constant of aberration; its value, according to the most recent determinations, is 20″·49. The Earth's diurnal rotation on its axis, combined with the motion of light, also causes an aberration of a similar kind; this is called the diurnal aberration. Its amount of course varies according to the latitude of the place of observation, being greatest at the equator, where the velocity produced by the Earth's rotation is greatest, and smaller the nearer we approach either of the poles, at which points, if observations could be made, it would be found to be nothing. At the latitude of Greenwich the constant of diurnal aberration amounts to $0''\cdot202$; the velocity of rotation there being very nearly a hundredth part of the velocity of the Earth's motion in its orbit.

CHAPTER XI.

THE CALENDAR.

THE words "almanac" and "calendar" had originally the same meaning; but, as often happens in such cases, usage has, in the course of time, given a slightly different meaning to each of them. An almanac as now understood means an annual volume containing information of various kinds specially useful in the year to which it applies. Every almanac contains a calendar which gives in a tabulated form for the year (divided into its months) the days of the week corresponding to each day of the month, with the dates of the principal anniversary days, and the times of the most important celestial phenomena, such as the rising and setting of the Sun and Moon, the Moon's changes, &c. "Almanac" comes to us from the Arabic, "al" being the definite article in that language and "manakh" signifying a calendar. The word "calendar" is from the Latin "calendæ," by which name the Romans called the first day of each month; and this is probably derived from a word "calare," to call (cognate with the Greek *καλεῖν*), because it was customary in very ancient times to call or summon people together at the beginning of a month to make known the calendar arrangements for that month.

Now it is evident that in distributing our time we must make its divisions correspond to those periodical celestial phenomena by which we are obliged to regulate the course and ordinary actions of our lives. The most important of these is the day, or period of time in which the Earth, by revolving on its axis and turning successively towards and from the Sun, causes the alternations of light and darkness. There is an unfortunate ambiguity in the word day, as it sometimes means the whole length of this revolution (which is arbitrarily divided into twenty-four hours, no natural divisions except that of light and darkness being possible) ; and sometimes that portion of it (which, in all parts of the world excepting those near the equator, is of very varying length) when it is light—the remainder of this period, when it is dark, being called night.

Besides the day there are two longer periods of time marked by celestial phenomena which are of great importance in the concerns of life. The first of these is the year; the length of this we have already given, and pointed out that the year of ordinary use (in which the changes of seasons are completed) is not precisely the period * in which the Earth revolves round the Sun, but a few minutes shorter, on account of a slow regular change in the position of the Earth's axis, the inclination of which to the perpendicular to its orbit, combined with the Earth's revolution round the Sun, causes the changes of seasons to take place. A year does not contain any exact number of days; and the year in question (called the tropical year) amounts to $365^d\ 5^h\ 48^m\ 46^s$. As it would never do in practice to make different years end at different parts of the day, most years (as we have already stated in the first chapter) are made to consist in the calendar of exactly 365 days, but occasionally one (usually each fourth) of 366 days is interposed, which keeps the designation of any part of the year always corresponding to the same state of the seasons.

The other natural division of time (called a month) is produced by the revolution of the

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* This is called a sidereal year, because at the end of it the Earth is in the same position with respect to the Sun and stars.

Moon in its orbit; it does not correspond (as we have already pointed out) to the actual period of the Moon's revolution round the Earth, but to that in which she successively occupies the same apparent position with reference to the Sun, which is longer than that of her orbital revolution on account of the Earth's having moved through a portion of its orbit round the Sun in the same time. This is called a lunation, or lunar (sometimes a synodic) month, and amounts (as stated in Chapter II.) to $29^d\ 12^h\ 44^m\ 2^s{\cdot}7$. About 12½ of these are completed in a year; but as it is of course desirable to divide our year into nearly equal portions, the whole of which are completed at the end of each year, our calendar months, as they are called, have very little real relation to these, but are purely artificial divisions, each of which (excepting the shortest month, February) is a little longer than a lunar month. Some nations, however, attributing greater comparative importance to these than we do, make their months really lunar months, and their years consist sometimes of twelve and sometimes of thirteen months.

The fact is said to have been first noticed by Meton, a Greek astronomer, that 235 lunar months are very nearly equal to 19 tropical years. The former, in fact, contain 6939^d 16^h 31^m; the latter 6939^d 14^h 27^m. From this it results that during each nineteenth year of our reckoning the position of the Moon with reference to the Sun will be very nearly the same on the same day of the year. Owing to the importance of this fact, the years were distributed into cycles of nineteen, each of which was called a Metonic Cycle from the name (as above mentioned) of the discoverer; and the number of any year in this cycle was called its Golden Number. The year called by us B.C. 1 corresponded to the number 1, and A.D. 1 to the number 2 in this cycle, and a cycle will be completed in the year 1899, so that the Golden Number of the present year (1889) is 9, and that of 1900 will be 1.

If a year be divided into periods of seven, in any one of which a week is completed, and the seven first letters of the alphabet be affixed to these in succession, each round beginning on the 1st of January (which therefore is always A), the same letter will always stand against the same day of the week, and that which stands against each Sunday in any year is called the Sunday (or Dominical) letter of that year. Now, as most years consist of 365 days, or one day more than a multiple of 7 (for $365 = 52 \times 7 + 1$), most ordinary years will begin and end on the same day of the week, and each of these will begin one day later in the week than did the preceding. In other words, in most cases if A be the Sunday letter of one year, that year begins and ends with a Sunday, and the next year beginning with a Monday, A will be Monday throughout that year, and its Sunday letter will be G, the first Sunday not falling until January 7. In the occasional years, however, which contain 366 days, two days more than a multiple of 7 will be completed in a year, and the Sunday letter of the next following year will not be the next preceding, but the next but one preceding alphabetical letter to what it is in the year itself, which is therefore called leap year, as the Sunday letter leaps in it over a letter in the alphabet backwards. As the extra or intercalary day is added not at the end of the year, but at the end of February (giving that month 29 instead of 28 days) it is usual to express this by giving two Sunday or Dominical letters to a leap year. Thus 1888 was a leap year; and the Sunday letter of 1887 was B; that of 1889 is F; and 1888 itself was said to have both A and G for Sunday letters.

CHAPTER XII.

SHORT SKETCH OF THE HISTORY OF ASTRONOMICAL DISCOVERY.

WE do not propose here to enter into any discussion of how much knowledge of astronomy may have been possessed by the ancient Egyptians, Babylonians, or other Eastern nations. Amongst the Greeks, Eudoxus, who was born at Cnidus in Caria about the year B.C. 409, is entitled to be regarded as the first astronomer. His works have not come down to us, but it is known that one of them was a description of the constellations, which is versified in the 'Phenomena'* of Aratus of Soli in Cilicia. The greatest of the ancient Greek astronomers was Hipparchus, who, though he was a native of Nicæa in Bithynia, made most of his observations at Rhodes. He was the first to form a systematic Catalogue of stars, induced to do so by the appearance of a new star in the heavens, which is thought to be the same as one recorded in the Chinese annals as having appeared in a year corresponding to B.C. 134, in the constellation Scorpio. The most probable date of the death of Hipparchus is B.C. 120. His Catalogue is only known to us by its being incorporated, with some modifications, into the great work of the Alexandrian astronomer Ptolemy, entitled Μαθηματική Σύνταξις, which we, in imitation of the Arabians, usually call the Almagest. Ptolemy, whose name is principally recognised by its connection with the Ptolemaic system, died early in the reign of the Emperor Aurelius, which commenced in A.D. 161. Amongst the Arabian astronomers the greatest name is that of Albatenius,* who flourished in the ninth century of our era. About a century later, the Persian astronomer Sûfi formed a Catalogue of stars from his own observations. Five hundred years afterwards, another Catalogue was made by, or rather under the auspices of, the Mongol prince, Ulugh Beigh † (as he is generally called), grandson of the famous Timour; it was formed by observations made at Samarkand, about the year A.D. 1433. Towards the end of the same century, the labours of Peurbach and Müller* prepared the way for Copernicus, who showed the simple explanation of the planetary motions which resulted from supposing the Sun to be placed in the centre of the system. His work, 'De Revolutionibus Orbium Cœlestium,' was published in 1543, in which year the illustrious author died. The foundation of the true theory of the solar system was thus laid, but the time for its establishment had not arrived. It was rejected by the great Danish astronomer, Tycho Brahé, in favour of a system called from him the *Tychonic*, by which the Moon and Sun were supposed to revolve round the Earth, and the planets round the Sun. Tycho's observations, however, furnished the means by which, less than twenty years after his death, Kepler deduced the laws according to which the planetary motions are performed. It was in the year 1618 that he discovered his third and last law, which shows the mutual correspondence existing in the motions of all the planets, and proves (though it was reserved for the genius of Newton to demonstrate that this consequence was involved in it) that they obey the same law of force directed towards the Sun. Meanwhile the equally famous Galileo* had been discovering the smaller system of moons which revolve round Jupiter as the planets do round the Sun, confirming by that and by other discoveries the truth of the Copernican system, and establishing the laws of motion, without a knowledge of which further progress in astronomy as a science was impossible. Galileo died in 1642: and in the same year was born Newton, the prince of philosophers, who discovered the law of gravitation, and showed how by its means the most important of the lunar and planetary motions could be explained. This was made possible by Picard's determination in France of the true size of the Earth, and by Flamsteed's observations of the Moon at Greenwich, which commenced in 1676, the observatory there having been founded the year before. Newton's great work, the 'Philosophiæ Naturalis Principia Mathematica,' was published (as is mentioned in a preceding part of this treatise) in 1687. Meanwhile Huygens had discovered one, and

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* This is the work which was quoted by St. Paul in his speech before the Areopagus at Athens (Acts xvii. 28).

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* So called from his birthplace, Baten, in Mesopotamia (Al, the definite article). His real name was Mohammed Abdallah.

† His real name was Mirza Mohammed Taraghai.

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* Usually called Regiomontanus, the name of his birthplace (Königsberg, in Franconia) translated into Latin.

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* Galileo Galilei is better known in England as Galileo than by the family name of Galilei.

Cassini four, of the satellites of Saturn ; and the former had explained the ring-like form of the appendage to Saturn, the existence of which had been first noticed by Galileo. It was not until some time after the death of Newton (which occurred in 1727) that his theory was futher developed and shown to be capable of explaining not only the principal courses, but the smaller modifications, of the planetary movements. This is due to the labours of several eminent mathematicians, but especially to those of Lagrange and Laplace. The 'Mécanique Analytique' of the former was published in 1787, and the 'Mécanique Céleste' of the latter was completed in 1825.

But towards the end of the eighteenth century arose an astronomer, Hanoverian by birth and English by adoption, who not only extended what had previously been supposed to be the boundary of the solar system, by the discovery of Uranus in 1781, but turning with unwearied diligence upon the sidereal heavens the powerful instrumental means constructed by himself, acquired for mankind a knowledge of the distribution and motions of the stars and worlds beyond our own system, which opened a new era in the history of astronomy. Sir William Herschel died in 1822, after having been elected the first President of the Royal Astronomical Society, which was founded in 1820. That Society published in 1827 a compiled Catalogue of Stars, which was the standard work of reference on the subject until it was superseded by the Catalogue of the British Association, published in 1845, and containing 8377 stars. Soon after this, the boundary of the solar system was still further enlarged by the famous discovery of Neptune (spoken of in Chapter V.) in 1846; and in the following year Sir John Herschel published the results of his observations at the Cape of Good Hope, where he had devoted some years to a diligent scrutiny of the stars and nebulæ only visible in the southern hemisphere, similar to that, initiated by his father and extended by himself and others, of the portion of the heavens which is visible in England. Early in the present century four new planets were discovered, revolving between the orbits of Mars and Jupiter, which are so much smaller than all the others, that distinct terms—planetoids or asteroids—were suggested for them. But as they differ from the others only in respect of their comparatively minute size, it is now more usual to call them small or minor planets. They remained four in number until 1845, when a fifth was found, since which discovery has been so rapid that no fewer than 283 members of the group are now known, and probably there are many others, although most of the later discoveries require a very powerful telescope to see them. The number of known bodies of the solar system has been further increased by the discovery of several more satellites (including two very tiny ones revolving round Mars, discovered in 1877), all which are referred to in previous parts of this treatise. And, as we have already mentioned (in Chapter VIII.), the accurate observations of modern times have also enabled astronomers at last to determine the approximate distances of some of the fixed stars; *a* Centauri, in the southern hemisphere, which is probably the nearest, being about 275,000 times as far off as the Sun, or nearly thirty billions of miles.

It is now nearly thirty years ago that a new branch of astronomy was opened up by the analysis of the light of the heavenly bodies by means of the spectroscope. This commenced with the investigations of Kirchhoff and Bunsen in 1860, but was brilliantly followed up by Dr. Huggins and the late Dr. W. A. Miller, and subsequently by others. Not only has it enabled us to learn much of the chemical constitution and condition of the worlds and other luminous objects both in and beyond our own system, but its later developments have revealed motions of several of the stars in the line of sight (in some cases approaching, in others receding from us), which could not be recognised in any other way. One very interesting discovery made by the aid of spectrum analysis is that the light of many of the nebulæ (as was alluded to near the end of Chapter VIII. in the case of the great nebula in Orion) does not proceed from stars, as was once supposed, but from incandescent or intensely heated matter in a gaseous condition. But, although in even the shortest sketch of the history of astronomy, reference to this subject could not be wholly omitted, it does not fall within our scheme to enter upon it in any detail here. Suffice it to mention that the first person who is known to have noticed (though it is not unlikely Newton had done so before) a few of the dark lines crossing the prismatic spectrum at definite distances, was our countryman, the famous Dr. Wollaston, in the year 1802; but, owing to the large number which were observed and their positions accurately measured by the celebrated German optician Fraunhofer in 1815, it is usual to call them Fraunhofer's lines. The measurement of the positions and distances of these lines in different spectra, and the comparison of the spectra of the heavenly bodies with those of incandescent terrestrial substances, have led to the important discoveries alluded to above.

ALPHABETICAL EXPLANATION OF THE ASTRONOMICAL WORDS AND TECHNICAL TERMS USED IN THE FOREGOING TREATISE.

APHELION (properly aph-helion), from the Greek, *ἀπό* (which becomes *ἀφ-* in composition before an aspirate), *from*, and *ἥλιος*, *the Sun:* the point in a planet's orbit where it is farthest from the Sun.

APOGEE, from the Greek *ἀπό*, *from*, and *γῆ*, *the Earth;* the point in the real orbit of the Moon, or the apparent orbit of the Sun, round the Earth, at which either is at its greatest distance from the Earth.

ASTRONOMY, the science of the stars; from Greek, *ἀστήρ*, *a star*, and *νέμειν* (whence *νόμος*, *a law*), *to distribute*, *tend* (as a shepherd).

BINARY, double, two-fold; from Latin, binarius, *consisting of two things.* Applied technically to two stars which are comparatively near, and found to be in physical connection with, each other.

BISSEXTILE, a name for leap year, derived from the Latin. The Romans added the intercalary day in leap year by reckoning the sixth day before the calends of March (corresponding to our 24th of February) twice over, calling the second day *bissextus* (or *bisextus*), whence the leap year itself was called *annus bissextilis* (or *bisextilis*).

COMET (Latin, cometa), from Greek, *κόμη*, the hair of the head, the first idea of comets being that they were stars with hair-like tails.

CONGERIES, a mass of particles ; strictly, a Latin word ; congeries, *a heap*, from con-, for cum, *together*, and gerere, *to carry*, *bring*.

CONSTELLATION, a group of stars; from Latin, con-, for cum, *together*, and stella, *a star*.

DENSITY, from Latin, densus, *thick*, *close*, cognate with Greek *δασύς*, *thick*. Technically applied to the degree of closeness with which matter is contained in a given bulk or size. *Mass* is the quantity of matter contained in a body, so that if this matter be compressed into a smaller space, the mass will remain the same whilst the density will be increased in proportion to the smaller space in which the mass is contained.

DISC, or disk, a round plate (Latin, discus, *a quoit, a plate*), from Greek, *δίσκος, a quoit*, connected with *δικεῖν, to cast, throw.* Technically applied to the round visible surface of the Sun or Moon, or (as seen with a telescope) of one of the large planets.

ECCENTRICITY, a departing from the centre, or the amount of such departure ; from Greek, *ἐκ, out*, and *κέντρον, centre.* Technically applied to the proportion which the distance between the centre and one of the foci of an ellipse bears to the semi-major axis, or half the longer diameter.

ECLIPSE, from Greek, *ἐκλείπειν*, to leave out, relinquish, quit. Applied to an eclipse (*ἔκλειψις*) because the Sun and Moon were supposed when eclipsed to quit their places in the sky. As all the planets and satellities in the solar system receive their light from the Sun, they cast conical shadows behind them on the side opposite to that body. When one of the satellites, as it moves in its orbit, becomes enveloped in the shadow of the planet around which it revolves, it is said to be eclipsed ; for instance, when the Moon is partly or wholly enveloped in the Earth's shadow, she is said to be eclipsed, partially or totally as the case may be. The shadows of the satellites are not long enough ever to cover wholly the bodies of their planets when interposed between these and the Sun. Thus the shadow of the Moon, even when she is nearest to the Earth and her apparent size is largest, can at most cover at a time only a portion of the Earth about 170 miles in diameter, so that, as the shadow moves on, the Sun appears to be totally eclipsed over a zone of the Earth of about that breadth, for a duration never exceeding a few minutes ; over a much larger zone on either side of this there is a partial eclipse of the Sun. When the Moon is nearly at her greatest distance from the Earth, her shadow does not reach its surface at all ; and if an eclipse occur at such a time, it can never be total anywhere. At places where it is central, a ring of sunlight is left uncovered by the Moon when she covers the rest of the Sun's body ; an eclipse of this kind is called *annular*, from the Latin *annulus*, a ring.

ELLIPSE, an oval figure ; Latin, ellipsis, Greek, ἔλλειψις, from ἐλλείπειν, *to leave in* or *behind*. A parabola is formed by cutting a cone parallel to one side, the edge of which section is a parabola ; an ellipse is formed by cutting the cone by a plane which makes a smaller angle with its base than one parallel to either side, whence the word.

FIXED STARS. The stars beyond our solar system are called *fixed*, because being at such enormous distances, they appear to us (after allowing for the effects of the known motions of the Earth) always in the same or very nearly the same places in the visible heavens. The apparently small motions which modern astronomy has discovered in some of them are called their *proper motions*.

FOCUS, a place where rays of light meet, from Latin, focus, *a hearth* or *burning-place.* An optical term transferred to mathematics and astronomy. The focus of a parabola is the point within it to which all rays of light falling upon it from a great distance and parallel to its diameter converge after reflection. An ellipse has two foci ; all rays of light diverging from either focus would, after reflection at the ellipse, converge to the other focus. All the planetary orbits are ellipses with the Sun in one focus ; those comets which move in a parabola have the Sun in its focus, but these do not return after having been once seen.

Gregorian Style *or* Reckoning. So called from Pope Gregory XIII., who introduced that reckoning of the calendar in 1582, by which there are exceptions to making every fourth year a leap year. If the year A.D. is divisible by 100 without remainder, it is not a leap year unless it is also so divisible by 400, when it is. Thus, A.D. 1900 will *not* be a leap year, but A.D. 2000 will be one.

Julian Style *or* Reckoning. So called from Julius Cæsar, by whom it was introduced and ordered to be observed. By it, *every* fourth year was a leap year, commencing with the year called B.C. 45 in Christian chronology, so that B.C. 1 and A.D. 4 were leap years, and every year which was divisible by four without remainder was a leap year. This reckoning was generally followed until the year 1582, in England until 1752, and is still observed in Russia and Greece.

Meteor, strictly any appearance in the sky ; from Greek, *μετέωρος* raised up above the earth, soaring in the air (*μετὰ*, *among*, and *ἐώρα*, collateral form of *αἰώρα*, *things suspended*, from *ἀείρειν*, *to lift*, *raise up*). Technically applied to luminous bodies sometimes seen moving in the upper regions of the Earth's atmosphere, their motion through which makes them luminous. They are sometimes called shooting stars.

METEOROIDS, from Greek, *μετέωρος* (see last paragraph), and *εἶδος*, *form.* Technically applied to those meteors which have been discovered to move in large streams round the Sun, and appear like meteoric showers when the Earth is passing through them, radiating from the point in the heavens toward which the Earth is then moving. The August meteoroids are often called Perseids, because they radiate from a point in the constellation Perseus; the November meteoroids Leonids, because they radiate from one in the constellation Leo.

NEBULA, properly a Latin word, cognate with the Greek, *νεφέλη*, *a little cloud*; technically applied to a mass of matter (sometimes consisting of a cluster of very distant stars) which resembles a small cloud in appearance.

NODE, from Latin *nodus*, a knot. Technically used for the points in the orbit of a planet where it crosses the plane of the Earth's orbit.

NUTATION, from Latin, nuto, *to nod, shake, swing to and fro;* an oscillatory motion of the Earth's axis, by which it periodically increases and diminishes its inclination to the plane of the ecliptic.

OPAQUE, originally a French word; from Latin, opacus, *shady.* Technically applied to a body which is not self-luminous or transparent, and can only become visible by reflecting rays of light which fall upon it. All the planets and satellites in the solar system are opaque, and receive their light from the Sun.

PARABOLA (see above under *Ellipse*); from Greek, *παρά, beside,* and *βάλλειν, to cast, throw*; of similar origin to "parable," but technically used for the figure formed by a plane cutting a cone parallel to one of its sides, the edge of which section is a parabola.

PARALLAX, from Greek, *παράλλαξις* (*παρά beside,* and *ἀλλάσσειν, to change, alter*), the apparent change in the place of a heavenly body produced by a real change of place of the observer. Technically, as applied to the bodies of our own system, it means the difference between their places as actually seen by us, and as they would be seen from the centre of the earth; as applied to the fixed stars, the difference between their places as seen by us on the Earth, and as they would be seen from the Sun, the centre of the Earth's motion. The former is called *geocentric*, the latter *heliocentric*, parallax.

PERIGEE, from the Greek, περί, *around*, and γῆ, *the Earth;* the point in the real orbit of the Moon, or the apparent orbit of the Sun, round the Earth. at which either is at its least distance from the Earth.

PERIHELION, from the Greek, περί, *around* and ἥλιος, *the Sun*; the point in a planet's orbit where it is nearest the Sun.

PHASE, from the Greek φάσις, an *appearance.* Technically applied to the varying apparent shape of the Moon and some of the planets, in consequence of a larger or smaller part of that half of their surfaces which is illuminated by the Sun being turned towards the Earth. Mercury and Venus, which move in orbits round the Sun within that of the Earth, exhibit all the phases of the Moon; but the planets which move in orbits beyond that of the Earth, can only become slightly gibbous in appearance. Indeed it is only Mars, the next planet outwards to our own, that can take that form to a sensible extent, the Earth being so near the centre of the orbits of the others (in proportion to the diameters of those orbits) that we practically have always the illuminated half of their surfaces turned towards us.

PLANET, a wandering star, from Greek, πλανήτης, *a wanderer*, a lengthened form of πλάνης, of which the plural πλάνητες was especially used to signify the planets. Technically applied to the solid spherical bodies of the solar system which move in regular orbits round the Sun.

SATELLITE, a follower, attendant, from French, *satellite*, a sergeant, or yeoman of the guard; Latin, *satellitem*, accusative case of *satelles*, *an attendant*, *life-guard*. Technically applied to the smaller bodies (formerly sometimes called secondary planets) which move round some of the large planets, as the Moon does round the Earth, of which it is a satellite.

SELENOGRAPHY, a description of the Moon's surface, from Greek, σελήνη, *the Moon*, and γράφειν, *to describe;* similar to Geography as applied to the Earth, from γῆ, *the Earth*, and γράφειν, *to describe.*

ZODIAC, an imaginary zone or band in the celestial sphere, extending about 8° on either side of the ecliptic. So called from the Greek ζωδιακή, formed from ζῴδιον, diminutive of ζῷον, *a living creature* or *animal*, because most of the constellations along the zodiac are supposed to represent animals or other living creatures. Indeed, this may be said to have been the case with them all, as Libra was formerly considered a part (the claws) of Scorpio.

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